Possible Expansion of Nuclear Energy:
An assessment of national capacities and imperatives for nuclear power implementation in non-nuclear countries

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Abstract
Growing concerns over energy security and climate change have lead to an increase in the interest in nuclear power development and the International Atomic Energy Agency (IAEA) reports that there are 48 countries interested in building their first nuclear power plant. This characterizes and evaluates Newcomer Countries in terms of their financial, institutional, and technical capacity to develop nuclear power, as well as the national imperatives to do so. To do this, the study reviews historical data to identify economic and political factors which facilitated the development of nuclear energy in countries with existing nuclear power program and compares these data to comparable data from Newcomer Countries. It finds that there are only 10 Newcomer Countries which are likely to implement nuclear energy, 13 Countries where nuclear energy implementation is possible, 10 Countries where pursuing nuclear energy is risky, and 15 countries where nuclear energy is unlikely. The results raise the question as to why so many countries with low capacity and imperatives for nuclear energy are interested in pursuing it. They also suggest that the support for developing nuclear energy be accompanied by an evaluation of the country's capacity and imperatives to pursue nuclear power such as the one presented here.

1. Introduction
Over the past decade, energy security and climate change have emerged among the top issues on the political agenda. With fluctuations in crude-oil prices of over 300% during the last 5 years (EIA, 2009) and concerns over long-term supply-security of conventional oil and gas reserves (IEA, 2008), energy security has emerged as a key strategic issue facing both the developed and developing world (Yergin, 2006). Concurrently, concerns over climate change continue to rise with the most recent International Panel on Climate Change (IPCC) assessment report stating that "warming of the climate system is unequivocal" and it is 90% likely that this trend is caused by human activities and will have severe irreversible consequences (IPCC, 2007). Within this context, nuclear power is an attractive electricity generation option because it offers significantly lower GHG emissions than conventional thermal power plants and also offers the benefit of supply security.

Fossil-fuel power plants emitted 41% of the global CO_2 in 2006 (IEA, 2008) and since nuclear power offers significantly lower GHG emissions than conventional thermal power plants[1], it has been proposed as a key of climate change mitigation (IEA, 2008; Pacala & Socolow, 2004; Sims et al., 2007) In the International Energy Agency (IEA) *World Energy Outlook* climate stabilization scenarios, nuclear energy capacity increases by between 50 and 87% by 2030 compared to a 23% increase in the reference scenario (IEA, 2008).

Nuclear power has also been proposed as a way to address current energy security concerns due to the security of uranium supply and the greater protection from raw material price fluctuations. Unlike oil and gas reserves, uranium is abundant and geographically distributed with a large portion of the resources located in stable democracies (NEA, 2008). Even in the face of large nuclear expansion, proven uranium reserves are estimated to last at least a century and most likely well beyond the next 100 years (Macfarlane & Miller, 2007; NEA, 2008). Nuclear energy also offers greater protection from commodity price

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[1] Life-cycle assessments of nuclear energy indicate that it emits between <1 and 50% of carbon dioxide (CO_2) per kWh when compared to natural gas and <1 and 20% of CO_2 per kWh when compared to coal-fired power plants (Sovacool, 2008).

fluctuations. In 2008, the International Atomic Energy Agency (IAEA) reports that a doubling of uranium prices resulted in a 5-10% increase in generating cost while a doubling for coal and gas led to a 35-45% and 70-80% increase respectively (IAEA, 2008a).

The increase in concern over climate change and energy security has lead to an increase in interest in nuclear power and the possibility of a "nuclear renaissance" has emerged as many governments are expressing interest in reviving or starting a national nuclear power program (Nuttall, 2004; Sauga, 2008; Wolfe, 2007).[2] The International Atomic Energy Agency (IAEA) reports that there are 48 countries which have contacted the agency for help in starting a nuclear power program (IAEA, 2008b). These countries, usually referred to as Newcomer Countries, vary greatly in economic and social development. As Figure 1 shows, they range from the high-income Persian Gulf States to low-income Sub-Saharan African countries. Since deploying nuclear power requires managing significant financial, institutional, and technical challenges and uncertainties, experts in the field have expressed doubts about the capability of these countries, to initiate a nuclear power program. In addition to skepticism about the capacity of countries to implement nuclear power, several experts in the field have expressed concerns about the risks associated with the spread of nuclear technology which would inevitably accompany introducing nuclear energy in new countries (Barnaby, 2009; Fréchette, 2008; National Academy of Sciences (U.S.). U.S. Committee on the Internationalization of the Civilian Nuclear Fuel Cycle, Committee on International Security and Arms Control, Policy and Global Affairs, National Academy Of Sciences, & National Research Council, 2008).

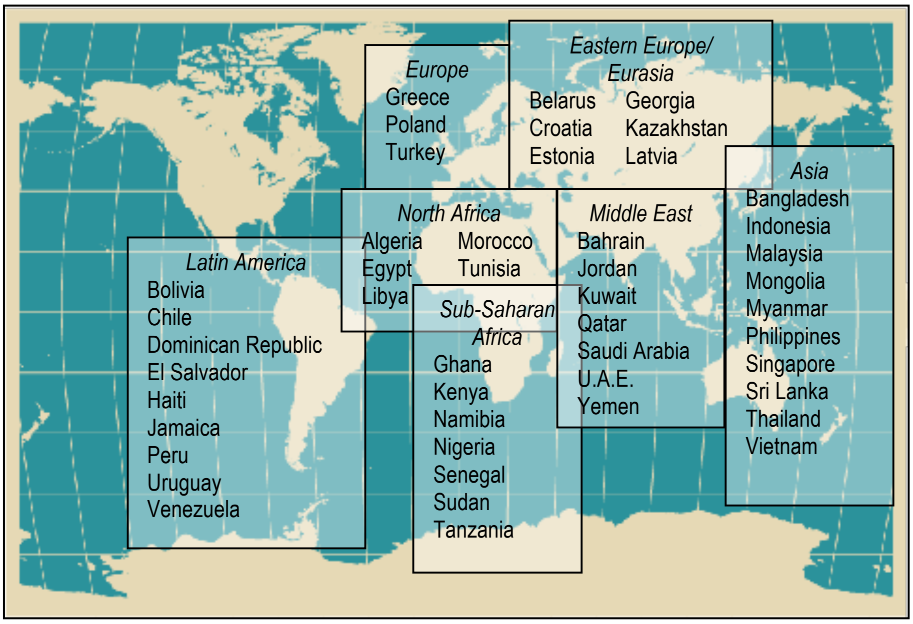

Figure 1 Nuclear Newcomer Countries
The countries which have expressed interest in acquiring their first nuclear power plant (IAEA, 2008).

Building even a single NPP requires significant financial, technical and institutional resources. Nuclear power is very capital intensive when compared to other forms of power and thus requires a large **financial** investment at the start of the project equivalent to approximately USD4,000/kWe (Du & Parsons, 2009; Harding, 2007). Given that most commercial NPPs generally have a capacity of 1 GW or greater, constructing a standard NPP generally costs about USD4 billion. Given that the IAEA does not recommend a single power plant to constitute more than then 5 to 10% of an electricity grid (IAEA,

[2] The "Nuclear Renaissance" also has several skeptics both in terms of the ability of nuclear power to address climate change (Lovins, Sheikh, & Markevich, 2009) and the veracity of the so-called "Nuclear Renaissance" (Parenti, 2008; Schneider, 2008).

2007a), the **technical** requirement for nuclear power implementation is an electricity grid bigger than 10 GW or international grid connections allowing for the sale of excess electricity. Finally, a country must have a sufficient **institutional** capacity to either manage a publicly-funded nuclear power program or attract private investment and gather international support.

In spite of a growing interest and concern in nuclear energy in Newcomer countries no study exists which evaluates Newcomer countries in terms of their capacities and imperatives. The IAEA has published several documents (IAEA, 2007a, 2007b, 2008) about considerations and milestones with developing nuclear power programs in Newcomer Countries and a series of regional studies was published in 2008 which characterizes the driving forces and challenges to instituting nuclear power in different regions (see Toth 2008 for a summary).

This study aims to bridge the aforementioned research gap with data and analysis of contemporary sources as well as by looking at the historical economic and energy trends in countries with existing nuclear programs at the time of development. It examines Newcomer Countries both in light of policy documents and from the perspective of the factors that drove nuclear energy to develop in countries with existing programs (so called Existing Nuclear Countries). This characterization can also help inform the non-proliferation literature that addresses drivers and predictors for nuclear weapons development by shedding light on the drivers for nuclear energy.[3] Neither historical nor contemporary research can enable us to predict the future, however this two-pronged approach will increase the understanding of if and how nuclear energy can develop in Newcomer Countries.

2. Methodology for Assessing Newcomers

While the dimensions of capacity and drivers for nuclear energy are broadly clear, the threshold at which a country is considered capable and sufficiently motivated to build and manage a NPP is difficult to define. For one, a country's **capacity** requirements are influenced by the national **imperative** to develop nuclear energy. Simply speaking, countries seriously *interested* in building an NPP are more likely to acquire, mobilize, and concentrate the necessary resources than countries lukewarm to the idea. Secondly, while there are indicators which can be used to quantitatively evaluate a country's capacity and imperatives for introducing nuclear energy, except for grid capacity, there is no objective minimum for the different aspects of either dimension.

2.1. Advantages and limitations of the comparing Newcomers to Existing

In order to contextualize Newcomer Countries' capacity and motivation for developing nuclear energy, this study presents a series of indicators which characterizes a country's financial, institutional, and technical capacity as well as their demand, energy security, and nuclear weapons considerations. The financial and institutional capacity data as well as the demand imperative and nuclear weapons considerations data are benchmarked against similar data for countries with existing nuclear power programs, or so-called Existing Countries, from the time of the start of construction of their first NPP. For technical capacity, the data are benchmarked against the IAEA guidelines for minimum grid capacity. The energy security imperative is not compared to an independent dataset but rather used to rate the relative energy security of different Newcomer Countries. The following two sections discuss the indicators used for each component and Table 1 presents a summary of selected indicators.

While the method of benchmarking Newcomer Countries against Existing Countries is useful to gain insight how nuclear energy may develop, it is important to note that the world today is significantly different than the world in which all of the existing nuclear programs developed. Nuclear energy emerged in the late 1950s following World War II and was a direct offshoot of nuclear weapons. Initially, the

[3] For examples of non-proliferation studies see: (Sagan 2000; Singh and Way 2004; Montgomery and Sagan 2009).

technology promised to supply the world with an abundant supply of electricity which would be "too cheap to meter" and between 1957 and 1976 twenty-five countries initiated nuclear power programs.[4] In the 1980s, the rate of new programs significantly dropped and only two programs were started during this decade with the last one in the world to be established in 1985 in China (data are from IAEA 2009). Since the Chernobyl disaster in 1986, no country has started a nuclear power program.

Thus the existing nuclear programs were all established in a world which was very different from today's. For one, the world was divided by the Cold War and as a result, the nuclear energy industry evolved with Soviet technology and expertise behind the Iron Curtain and primarily Western technology in the West. Secondly, electricity production was operated by state-run monopolies, both in the centrally planned economies and capitalist democracies, where the consumer bore most of the financial risk. Thus, while the past cannot serve as an exact parable to the present, it can provide insights into how and if nuclear power might develop in Newcomer Countries.[5]

2.2. Capacity Indicators

Indicators for **capacity** were reviewed for the main issues identified by the IAEA as key infrastructural considerations and included data reflecting: technical compatibility, financial capacity, human resources, physical infrastructure for transport of materials and supplies, the legal and regulatory framework, and facilities for processing radioactive waste (IAEA, 2007b). These infrastructural issues are evaluated under the assumption that a country is already stable politically, economically and socially (IAEA, 2007b). With the exception of grid capacity, the IAEA's evaluation criteria with regard to different infrastructural issues is qualitative and based on a review government documents and activities (IAEA, 2008). The capacity evaluation within this study takes a different approach: the capacity indicators are quantitative and aim to evaluate the relative "readiness" or "ability" of a country to implement nuclear power.

The two main technical requirements for implementing nuclear power are a reliable grid which is large enough to accommodate a standard NPP (IAEA, 2007b). A single power plant is not recommended to provide more than 5-10% of the regional grid capacity, thus given that standard nuclear reactors are generally 1 GW or larger, this can pose a problem for countries with small power grids. Since initiating a nuclear power program takes between 10 and 15 years (IAEA, 2007a), the year that the grid size is projected to exceed 10 GWe was calculated.[6] If the grid size is not projected to exceed 10 GWe within the next 15 years, the country was evaluated for the strength of international grid connections. This evaluation was completed by ranking countries as having "strong" or "weak" international grid connections and was done by reviewing available data for international grid connections as well as IEA

[4] A *New York Times* article in 1955 claimed that "nuclear energy promises to restore the balance between the "have" and "have not" nations of the world by providing an abundant, virtually limitless source of energy, enough to raise the standard of living of every nation in the world to heights undreamed of" (Laurence, 1955). Lewis L. Strauss, the chairman of the Atomic Energy Commission is famous for saying, nuclear energy which would be "too cheap to meter" (Laurence, 1955).

[5] It should also be noted that three of the original countries with nuclear power (the USSR, Czechoslovakia and Yugoslavia) broke apart and two of the original countries (Germany and West Germany) reunited in the 1990s, thus increasing the number of states with nuclear power from 27 to 30.

[6] The projected national generating capacities from now until 2030 were calculated by assuming linear growth and converting the average growth in electricity consumption in kWh to the equivalent installed generating capacity (data from World Bank, 2009). The average observed maximum output of a national electricity systems was calculated to be approximately twice the annual consumption (calculation based on data from World Bank, 2009). Thus, the annual consumption was doubled and divided by 8,760 (the number of hours in a year) to convert from GWh to GWe (calculations done with capacity data from EIA 2008; and consumption data from World Bank 2009).

electricity trade data. No technological indicators were used for Existing Nuclear States since historically, the competitive size of NPPs was smaller. No sufficient indicator was found to evaluate grid reliability.[7]

National financial capacity for national nuclear power development entails both allocating an initial investment into creating the regulatory, legislative and basic physical infrastructure to support the development of a NPP as well as financing the construction of the first NPP. The initial investment general comes from the government while financing the nuclear power plant can come from either private or public sources (IAEA, 2007b). Thus a country's indigenous resources as well as its attractiveness to investors determines its financial capacity. The two main financial indicators which are used are **GDP** and **GDP/capita PPP**. Foreign Direct Investment/capita was also used as an indicator for investment attractiveness in countries in countries with borderline financial capacity. The GDP indicators measure the absolute size of a country's economy as well as the population-proportional size a country's economy and are used to evaluate the financial resources which could potentially be dedicated to the development of nuclear power. The current data are benchmarked against historical values of GDP and GDP/capita PPP for Existing Nuclear States. For Existing Nuclear States, real GDP was chosen over GDP PPP because initially, countries generally need to import nuclear technology and expertise from abroad (IAEA, 2007a). For former socialist states, however, GDP PPP was used. This was done since Socialist states operated in an economy which was largely isolated from the West and relied solely on Soviet technology.[8]

Except for the use of FDI/capita for Newcomers with borderline financial capacity, the investment attractiveness of a country was not measured directly, however, three proxies were used. The link between investment attractiveness and a country's governance or institutional capacity is well established thus the two measurements of institutional capacity (discussed below) also indicate a country's investment attractiveness. The other data which was probed to analyze a country's investment attractiveness was to examine the ownership arrangements for Existing Countries and how these ownership arrangements relate to their respective GDPs and institutional capacity ratings.

As discussed above, a country's institutional capacity has a large influence on its investment attractiveness. In countries with existing nuclear power programs, gathering investments for nuclear power programs is dependant on stable and reliable regulatory procedures (Finon & Roques, 2008; Nuttall & Taylor, 2008). Since the commitment to and reliability of a country's nuclear regimes cannot be evaluated for nuclear Newcomers, indicators related to the general institutional capacity were evaluated. The indicator used is the Government Effectiveness Indicator which measures "perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" from the World Bank's Governance Indicators series (Kaufmann, Kraay, & Mastruzzi, 2008, p. 7). In other words, it measures the amount of confidence that government policies are effectively and fairly designed, implemented and enforced over-time.[9] Since the Government

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[7] "Value lost due to electrical outages" from the World Development Indicator (2009) database was considered, however it was discarded due to insufficient data and because two Existing Countries had high values indicating that low value lost due to electricity outages is not a good measure of grid reliability for the safe operation of a NPP.

[8] Except for an initial relationship between Romania and Canada, the nuclear energy programs in the Former Socialist States were all extensions of Soviet technology and expertise and were under Soviet management (Davey, 1982; Socor, 1985). A sensitivity analysis, the results of which are included in the results section, was run on this decision.

[9] In addition to the Government Effectiveness indicator, the World Bank's Regulatory Quality Indicator, Rule of Law Indicator, and Control of Corruption, as well as the ICRG Bureaucracy Quality Indicator were considered for this. The other indicators were ruled out on both theoretical and practical grounds. Theoretically, they either measured a phenomenon very similar to the Government Effectiveness Indicator or a phenomenon not with less relevance to the development of nuclear power. For example, Regulatory Quality Indicator was rejected because it primarily focuses on regulations which are relevant to small and medium-sized enterprises (SMEs). Practically the other indicators were rejected because they all displayed a high correlation coefficient with the Government Effectiveness Indicator. The other World Bank Indicators all had a correlation coefficient greater than 0.90 for the group of Newcomers and the ICRG Bureaucracy Quality Indicator had an r-value of 0.80.

Effectiveness indicator measures the perception of the quality of public services and the ability of the government to keep these services separate from politically-motivated actions it is applicable in two main ways. First, nuclear power is inherently dependent on existing infrastructure such as roads and highway systems to transport construction and operation materials. Thus, the capacity of a government to manage public services will have an influence on the ability of a government to provide supportive infrastructure which a NPP requires. Second, the perception of amount of independence of public services will influence the perception of reliability of commitment to nuclear power. Thus as an indicator this measures the perception of existing infrastructure and the confidence in the government to be able to maintain public services.

Since historical institutional capacity data is not available for Existing Countries from the time of nuclear power implementation, the Government Effectiveness Indicator is benchmarked against current data for Existing Countries and the ownership arrangements within those countries. Ostensibly, for a country to get private investment in its first NPP, the institutional capacity must be *at least as* good as the institutional capacity of those countries with operating nuclear power programs that have private ownership.

The other institutional indicator which is used is the World Bank's Political Stability Indicator. This indicator was chosen because a Newcomer's political stability will influence its ability to gain support for its national nuclear program from investors and international institutions (IAEA, 2007b). The political stability ratings are benchmarked against the occurrence of a violent conflict or regime change within 10 years of the start of construction of the first nuclear power plant within Existing Countries.[10] The World Bank's Political Stability Indicator reports a measurement of the perception that a government will be overthrown by violent means (Kaufmann et al., 2008).

Thus, this study benchmarks the current measurement of *perceptions* of political instability against the historic *presence* of a violent event. The benchmark value was determined by comparing the presence of a violent event during the last 10 years against the Political Instability Ratings. The percentage at which the two lists diverged was at the 20% political stability rating. In the bottom quintile 10 of the 14 countries experienced a significant violent event within the last 10 years (PITF, 2008). This proportion drops to 12 out of 20 in the bottom quartile of countries. Thus, for the purposes of this study, countries were classified as unstable if their political instability rating is less than 20%.[11]

2.3. Imperative Indicators

The main strategic reasons for the pursuing nuclear energy include: a lack of national energy resources, a desire to decrease import dependency and increase diversity of energy resources, as well as the mitigation of local and global air pollution (IAEA, 2007a; Toth, 2008). In addition to the stated national imperatives related to energy demand and supply, unlike other forms of energy, nuclear energy can also be related to nuclear weapons. As a result, the driving forces behind nuclear energy also sometimes include unstated drivers due to the inevitable relationship between nuclear energy and nuclear weapons. These tacit motivations are difficult to identify, however, they can act as a strong driver since they penetrate, at least in terms of perception, to a state's traditional security imperative. This section will start by addressing the indicators used for the imperatives related to energy supply and demand and end with a discussion of tacit motivations related to nuclear weapons and how these were accounted for in this study.

Two metrics were used to measure the demand imperative: the **proportional** electricity growth rate and the **magnitude** of electricity growth rate. Even though arguments for nuclear power often cite growing

[10] The occurrence of a violent conflict or a regime change was identified by using the catalogue of state conflicts (PITF, 2008).

[11] The one exception is Georgia whose political stability rating was 24. However, this rating was from before the recent war so it was reclassified as "unstable".

"energy" demands, since this study focuses on the use of nuclear power for electricity production, it limits the demand imperative to the electricity sector. Both the proportional and magnitude of electricity growth is used because, several of the countries with high proportional growth rates have such small economies that the magnitude of growth is very low. For example, even though Senegal has a growth rate of 8.4% per year, the magnitude in growth is equivalent to about 1/50th of the electricity produced from standard 1 GW NPP. Conversely, many of the largest economies, have low proportional growth rates with a very large magnitude of growth. For example, even though Poland's growth rate is only 2%, the magnitude of growth of electricity consumption is equal to about 1/3 of the annual electricity produced from a standard 1 GW NPP. For this study, countries whose new electricity consumption would consume the electricity produced from a new NPP within the next 15 years are considered to have a sufficient growth imperative to implement nuclear power.

Two commonly cited reasons for pursuing nuclear energy are related to energy security considerations and include the desire to increase both energy independence and supply diversity which are two components commonly proposed as measurements for national energy security (for examples of diversity see: Bazilian & Roques, 2008; Jansen, Van Arkel, & Boots, 2004; Stirling, 1994, 1998; for examples of import dependence see: Röller, Delgado, & Friederiszick, 2007; Alhajji & Williams, 2003; Scheepers, Seebregts, de Jong, & Maters, 2006, 2007). Since this study focuses on nuclear energy for electricity production, the **fuel-import dependency of the electricity system** and the **fuel-diversity of the electricity system** are used to measure relative national energy security of Newcomer Countries.

The import dependency of the electricity system was determined by calculating the percentage of imported fuel for oil, gas and coal and then proportionally scaling those energy sources to the total amount they contribute to the domestic electricity supply. The percentage of imported coal, crude oil and gas was calculated using 2006 data from the IEA Balance statistics website (IEA, 2009a). For each fuel source the production of a given fuel source in a country was divided by the sum of the production and the imported quantity to calculate the import dependency of a given fuel source. For oil, crude oil was used instead of the petroleum products category because it was assumed to be more representative of a country's indigenous resources rather than petroleum products which would be more representative of a country's processing capacity. If no crude oil trade was reported, the oil for electricity plants was assumed to be completely imported. The representative proportion of the electricity system of each fuel type was computed by dividing the number of GWh produced by a given fuel source in 2006 by the total domestic supply for 2006.

Like the import dependency indicator, the diversity indicator only included the electricity system for the reasons discussed above. To calculate the diversity of the electricity system, the Shannon diversity index is used which is commonly used in studies of energy security and diversity (APERC, 2007; Jansen et al., 2004; Stirling, 1994). The formula for the **Shannon diversity index** (Shannon & Weaver, 1963) is as follows:

$$DI = -\sum (p_i \ln p_i)$$

where:
DI = Diversity index
p_i = share of primary energy source "i" in the electricity mix
i = 1….M: primary energy source index (where M is the total number of sources)

In order to calculate the Shannon diversity index this study used 2006 data from the IEA database of electricity data (IEA, 2009b). The IEA reports 13 individual sources of electricity production: coal, oil, gas, biomass, nuclear, hydro, geothermal, solar PV, solar thermal, wind, tidal, and other sources. For simplicity, this study combined solar PV and solar thermal into one just solar energy source. Within the 48 newcomer states, ten of the twelve energy sources are represented (obviously nuclear is excluded as is tidal energy). Thus, the maximum value for the Shannon diversity index within the newcomer states is

2.30. The energy security of countries was rated as either low, medium, or high based on both of these metrics.

In addition to energy security, nuclear energy is related to traditional security considerations. While the system of safeguards and inspections is much more developed than it was during the 1960s and 70s when most of the existing nuclear programs were developed, the inevitable link between civilian nuclear power and nuclear weapons still exists. This study codes countries that developed nuclear weapons as being driven by the traditional security imperative at the time of development of nuclear energy. For countries that do not have nuclear weapons, this study relied on published analysis of historical nuclear weapons considerations for both Existing and Newcomer Countries. For Existing countries, if there is a published account of nuclear weapons considerations during or before the development of nuclear energy, the country is coded as having nuclear weapons considerations. Newcomer Countries are coded as having nuclear weapons considerations when there is historical evidence of pursuing the development of nuclear weapons.[12]

Even though several indicators were reviewed to address the environmental motivations for nuclear energy, none were considered to be suitable. For local air pollution, there is not a national indicator which reflects the average concentration of pollutants from power plants. Sulfur dioxide and nitrous oxide emissions are only available on a per-capita basis and the concentration of particle pollution is influenced by too many natural sources to adequately reflect the local-pollution imperative. Furthermore, while alleviating local air pollution is a convenient benefit of nuclear power, there are cheaper methods available.

For the relationship between emissions concerns and nuclear power, there was no way which was identified to adequately evaluate a country's interest in decreasing their emissions. With the uncertainty of the future climate agreement, there is no way to measure a country's commitment and interest in reducing emissions. Furthermore, even if there were a quantitative measure of commitment, there is no guarantee that reducing GHG emissions would actually correspond to a strong national imperative for nuclear energy. To date, nuclear power is the only technology to date excluded from the Clean-Development Mechanism for being inconsistent with sustainable development goals (de Coninck, 2008) and there is no indication that this status will change.

Table 1 Summary of selected Indicators

Existing Countries	Newcomer Countries
Technical Capacity	
• Not Applicable (see text)	• Current and 15-year projected electricity grid size • Strength of international connections
Financial Capacity	
• GDP at time of construction of first NPP • GDP/capita PPP at time of construction of first NPP	• GDP • GDP/capita PPP
Institutional Capacity	
• Current Government Effectiveness Indicator • Occurrence of violent conflict or regime change within 10 years of constructing its first NPP	• Government Effectiveness Indicator • Political Stability Indicator

12 Singh and Way (2004) define three levels of interest in nuclear weapons: "explore", "pursue" and "acquire" to measure the determinants of nuclear weapon development, however for this study this level of division is deemed unnecessary.

Existing Countries	Newcomer Countries
Energy Demand Imperative	
• Proportional Electricity Demand Growth Rate	• Proportional Electricity Demand Growth Rate • Magnitude of Electricity Demand Growth
Energy Security Imperative	
• Not available	• Diversity of the primary sources of the electricity system • Import dependency of the primary sources of the electricity system
Traditional Security Imperative	
• Evidence of historical interest in developing nuclear weapons	• Evidence of past or current interest in developing nuclear weapons

3. Results

3.1. Historical drivers for nuclear energy

Historically nuclear power programs are associated with nuclear weapons considerations and periods of high growth in electricity consumption. As shown in Table 2, of the 24 countries for which there is historical electricity data, 23 of them were experiencing growth rates in electricity consumption greater than 5% and six of the countries had growth rates in electricity consumption which exceeded 10%. In contrast, the average world growth rate in electricity consumption between 1971 and today was about 3%.[13] Additionally, in general, most of these growth rates were significantly higher than the average growth rate over the last 30 to 60 years.[14]

Table 2 Historic economic and electricity consumption growth rates for Existing Nuclear States around the time of construction of their first NPP

Country	Year Construction started on first NPP > 100 MWe	5-year average electricity consumption growth rate during construction of the first NPP*	Average electricity growth rate from 1960-2006 for OECD countries and 1971-2006 for non-OECD countries
U.K.	1957	7.5%[A]	3.8%
U.S.	1957	6.8%[A]	3.8%
Former Soviet Union	1958	14.4%[D]	NA
Former Czechoslovakia	1958	NA	NA
France	1958	7.8%[A]	4.4%
Canada	1960	6.2%[A]	3.8%
Japan	1961	11.4%[A]	5.3%
Former W. Germany	1962	11.4%[A]	3.8%
Spain	1964	11.8%[A]	6.6%
Switzerland	1965	5.1%[B]	3.1%
Pakistan	1966	7.1%[C]	7.9%
Sweden	1966	6.4%[B]	3.5%

[13] This is a rough estimate calculated from World Bank WDI Data from 1971 to 2006 (World Bank, 2009).

[14] In 7 countries, the electricity consumption growth rate around the time of start of construction of the first NPP was twice the national average; in 10 countries the growth rate was over 50% of the average; and in three countries the growth rate is between 30% and 50% higher than the average.

Country	Year Construction started on first NPP > 100 MWe	5-year average electricity consumption growth rate during construction of the first NPP*	Average electricity growth rate from 1960-2006 for OECD countries and 1971-2006 for non-OECD countries
Argentina	1968	6.0% C	4.7%
India	1968	6.6% C	6.9%
Belgium	1969	7.2% B	4.2%
Netherlands	1969	10.1% B	4.5%
Former E. Germany	1970	NA	NA
Bulgaria	1970	8.0% C	1.7%
Brazil	1971	8.5% C	6.5%
Finland	1971	9.1% B	5.4%
South Korea	1972	15.9% C	11.2%
Hungary	1974	7.5% B	3.1%
Former Yugoslavia	1975	NA	NA
Mexico	1976	9.5% B	6.1%
South Africa	1976	8.9% B	4.4%
Romania	1982	4.1% B	1.5%
China	1985	6.1% B	9.2%

**Where possible, the average electricity growth rate was calculated for the 5 years preceding the construction of the first NPP great than 100 MWe using World Bank data (World Bank, 2009). Often, due to data limitations this was not possible. As a result, each growth rate figure is coded with the source and time range for growth. The codes are as follows. A: Growth rate is calculated from 1960 to 1965 with World Bank Data. B: Growth rate is calculated for five years preceding the start of construction of the first NPP using World Bank Data. C: Growth rate is calculated from 1971 to 1976 using World Bank data. D: Growth rate is calculated from 1955 to 1960 using (Bogomol'nyi, 1976).*

In addition to a strong demand imperative, there is evidence that military concerns drove much of the interest and nuclear energy (Puig, 2005; Kåberger, 2007; Walker, 1992). Eight of the 27 Existing Countries successfully developed nuclear weapons.[15] In addition another eight considered the development of nuclear weapons as evidenced by active support of development of the bomb or the presence of a combined civilian/military nuclear program.[16] Thus of the 27 countries with nuclear power sixteen considered or actively pursued the development of nuclear weapons.

3.2.Newcomer Countries' capacity in context

This section discusses the capacity evaluations for Newcomer Countries using the data from Existing Countries.

Of the 48 Newcomer Countries: 16 currently have grid capacities which exceed 10 GWe, 11 have grids which will likely exceed 10 GWe within the next 15 years, 10 have grid connections which could potentially be used to sell electricity to, and 11 have grids which are likely to continue to be too small and disconnected to be successfully implement a standard NPP within the next 15 years.

[15] These include: the U.S.A., the U.K., the U.S.S.R., France, Pakistan, India, China, and South Africa (which is the only country to ever give up its nuclear weapons.)

[16] These countries include: Argentina, Brazil, Korea, Romania, Spain, Sweden, Switzerland, and Yugoslavia. Data are from: (Bunn, 2001; Kristensen & Godsberg, n.d.; Martin, 1996; Puig, 2005).

Table 3 Technical capacity results for Newcomers (for grid connection sources see Appendix 1)

Low Technical Capacity	**Medium Technical Capacity**	**High Technical Capacity**	
Current grid > 10 GWe	**Unlikely to have suitable grid**	**Prospective Grid > 10 GWe in <15 years**	**Small grid, but strong grid connections**
Chile	Bolivia	Algeria	Croatia
Egypt	Ghana	Bahrain	El Salvador
Greece	Haiti	Bangladesh	Estonia
Indonesia	Jamaica	Belarus	Georgia
Kazakhstan	Kenya	Dominican Republic	Latvia
Kuwait	Mongolia	Jordan	Namibia
Malaysia	Myanmar	Libya	Qatar
Philippines	Senegal	Morocco	Sri Lanka
Poland	Sudan	Nigeria	Tunisia
Saudi Arabia	Tanzania	Peru	Uruguay
Singapore	Yemen	Syria	
Thailand			
Turkey			
United Arab Emirates			
Venezuela			
Vietnam			

The financial capacity data for both Existing and Newcomer Countries displays a wide range of GDP and GDP/capita PPP. As shown in Figure 2, in the Existing Countries, the range is significantly narrower if only the states with nuclear weapons considerations are included. The financial capacity for all Existing Nuclear States ranged from 13 billion USD_{2000} to over 2 trillion USD_{2000} and the GDP/capita PPP values ranged from \$700/capita to \$22,000/capita. However, if nuclear weapons states and states with former nuclear weapons aspirations are excluded, the minimum GDP for a state implementing nuclear power jumps from 13 billion USD_{2000} to 53 billion USD_{2000} and the minimum GDP/capita PPP jumps from \$700/capita to \$6,000/capita.[17] This result suggests that when nuclear weapons aspirations or capabilities accompany the desire to pursue nuclear energy, the financial capacity requirements are lower than when nuclear energy is only pursued for civilian purposes.

[17] If the available real GDP values are used for the former socialist states, Hungary and Romania drop below Finland's minimum GDP of 53 billion USD_{2000}. Hungary's real GDP was 31 billion USD_{2000} and Romania's was 43 billion USD_{2000} the year that they began construction on their first NPP. While no data was found on Romania, it is clear that Hungary struggled financially to complete their NPP. In spite of support from a significant cooperation agreement from the USSR (KK, 1974), a report from Radio Free Europe published in 1985 states that the project suffered from cost over-run and time delays which not only affected the Nuclear plant in Hungary but also had a negative impact on other government investment activities (Hudson, 1982).

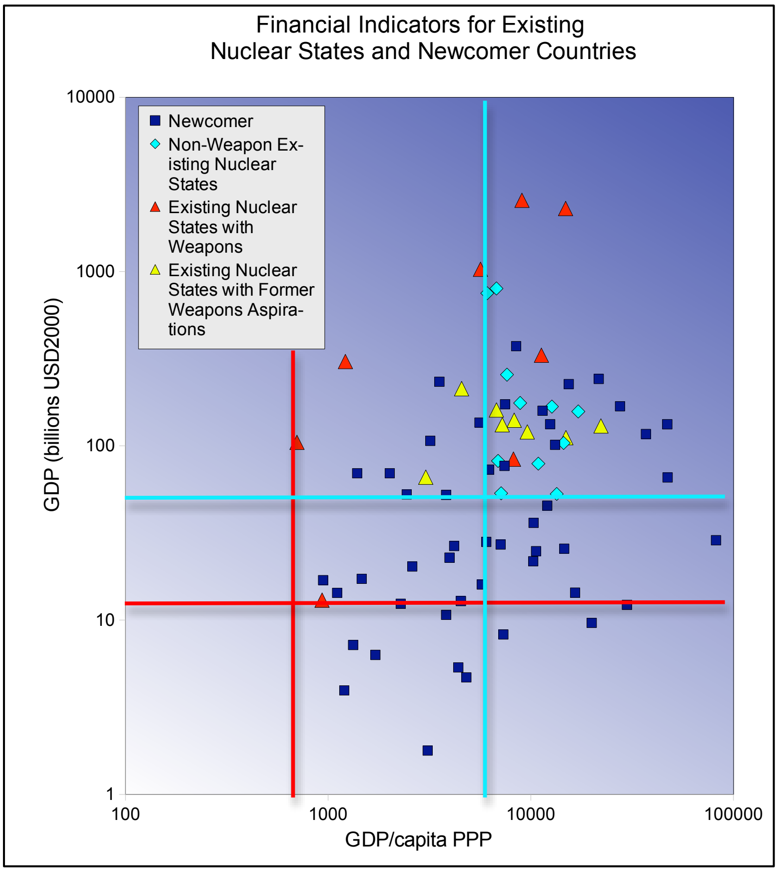

Figure 2 Financial capacity indicators for Existing Nuclear States and Newcomers
2007 GDP data are compiled from (World Bank, 2009; Maddison, 1995, 2003) and are real GDP values except for the former Eastern-block states which are GDP PPP values. Data are all converted to USD_{2000} using (Sahr, 2009). GDP/capita PPP data are from (Lindregen, 2009).

Thus, if we take 50 billion USD_{2000} as the minimum GDP for building a NPP, only 20 of the 48 Newcomer Countries exceed this threshold; seven of these countries fall below the GDP/capita PPP threshold of non-weapon Existing states and 13 countries fall above.

For the institutional capacity indicators, the range of values for nuclear Newcomers is also significantly wider than for Existing Countries. Two-thirds of the Existing Countries fall in the top quartile of Government Effectiveness and the lowest Government Effectiveness rating for Existing Countries is 28 (Pakistan). In contrast, only 5 of the Newcomer Countries fall in the top quartile and 11 fall in the lowest 25% of countries in terms of Government Effectiveness. Within the Existing Countries with NPPs owned and operated by private companies, Spain has the lowest Government Effectiveness rating of 81 (out of 100). For Existing Countries with mixed ownership, China has the lowest Government Effectiveness rating of 61.

The comparison between Existing and Newcomer Countries shows a similar disparity in terms of political instability. Of the 27 Existing Countries, only 5 went through a period of political instability within 10 years before or after implementing nuclear power. This instability can be classified as military-lead (in the case of Argentina, Brazil, India, and Pakistan or democracy-led in the case of Czechoslovakia. For India and Pakistan, the instability included internal tensions as well as the 1965 Indo-Pakistan War and for both Argentina and Brazil, the instability included a military coup. In Czechoslovakia, the political instability was lead by Communist reformers during the "Prague Spring" of 1968. In three of the four countries with military-led instability, the pursuit of nuclear weapons accompanied the development of nuclear energy (Bunn, 2001; NTI, 2009). Pakistan is now a weapons state, however, several scholars have stated that Pakistan did not begin developing nuclear weapons until 1972 even though it began construction of its first NPP in 1966 (Ahmed, 1999; Nizamani, 2000). However, given their anomalously low financial capacity when compared to the historical data of other Existing states and their political tensions with India, its possible that nuclear weapons was a tacit motivation.

While there are only a few examples of Existing Countries exhibiting political instability at the time of the start of construction of their first NPP, 14 of the 48 Newcomers are in the bottom quintile of all countries with the Political Instability Index. These countries are classified as unstable while the other Newcomer Countries are classified as sufficiently stable to implement nuclear energy.

Table 4 presents a summary of the capacity evaluation for Newcomer Countries.

Table 4 Capacity summary for Newcomers

	High Institutional Capacity; Medium to Low Financial Capacity		Political Unstable	
Sufficient Capacity in All Areas	**Sufficient Technical Capacity**	**Insufficient Technical Capacity**	**High Financial & Technical Capacity**	**Low Financial and Technical Capacity**
Greece	Peru	Tunisia	Indonesia	Sri Lanka
Singapore	Qatar	Dominican Republic	Thailand	Sudan
Saudi Arabia	Morocco	Jamaica	Venezuela	Georgia*
U.A.E.	Libya	Tanzania	Philippines	Bolivia
Poland	Kazakhstan	Senegal	Nigeria	Kenya
Kuwait	Belarus	Ghana	Algeria	Myanmar
Turkey	Uruguay	Mongolia	Bangladesh	Yemen
Malaysia	Bahrain			Haiti
Egypt	Latvia			
Chile	Syria			
	Vietnam			
	Estonia			
	Croatia			
	Jordan			
	El Salvador			
	Namibia			

**Georgia is rated as having sufficient technical capacity.*

3.3. An evaluation of Newcomer Countries' imperatives for nuclear energy

This section presents the imperative results for Newcomer Countries. While a country should ideally have high capacity in all three areas, in order to implement nuclear energy, a country only needs one imperative to pursue its development. Of the Newcomer Countries, 23 have a high demand imperative with growth rates ranging from 5%-14% and 0.1 GWe-1.3 GWe of equivalent installed nuclear power per year. Another 6 countries have a moderate growth imperative with growth rates ranging from 2%-5% per year and 0.1-0.4 GWe of equivalent nuclear power. See Appendix 2 for data. Nineteen of the Newcomer Countries have low energy supply security of their electricity system when evaluated with import dependency of the fuels and diversity. (See Figure 3 for the groupings and data).

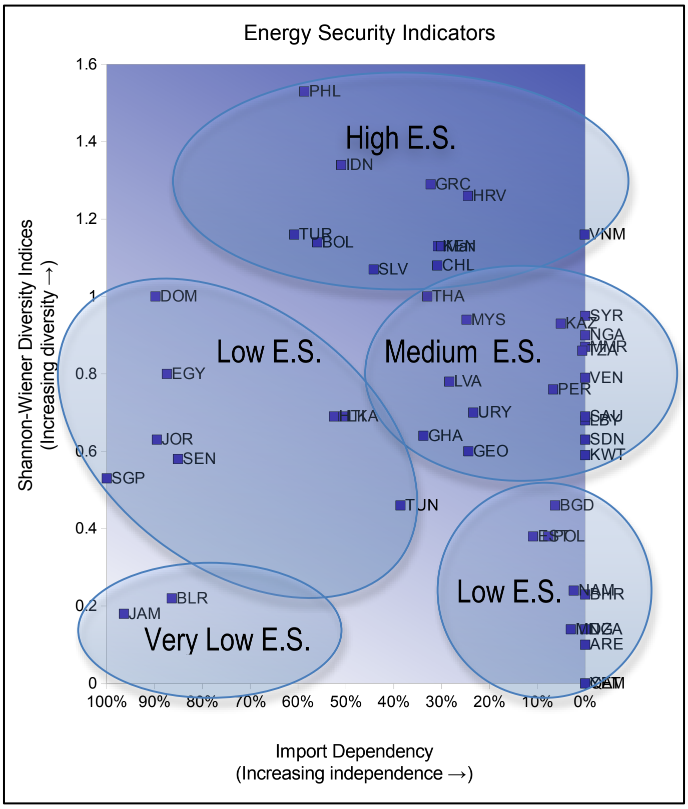

Figure 3 Energy Security Indicators
Graph is produced from data compiled from (IEA, 2009c, 2009a)

While many experts in the field argue that civilian nuclear assistance and development does not lead to nuclear weapons development, a recent study found that civilian nuclear assistance significantly increases proliferation risks (Fuhrmann, 2009).

Out of the Newcomer Countries, Algeria, Egypt, Indonesia, Libya, and Syria have at some point in history explored or actively pursued the development of nuclear weapons (Bunn, 2001; Jones, McDonough, & Spector, 1998; NTI, 2008) and Myanmar is thought to be actively pursuing the development of nuclear weapons (NTI, 2009). The IAEA has stated that, "although civil nuclear power plants in themselves do not pose an increased proliferation risk, an increase in the amount of nuclear material in use may intensify the risk of diversion to non-peaceful uses or terrorism" (IAEA 2008c, 33).

Furthermore, it is clear that the interest in nuclear energy closely follows developments in nuclear weapons. With Arab leaders throughout the Middle East and North Africa concerned about the possibility of Iran as a nuclear weapons state, the interest in nuclear energy in the MENA region has blossomed over the past decade. With the potential emergence of Iran as a new nuclear-weapons power, its neighbors have a strong incentive to establish nuclear power programs as a security hedge (Fitzpatrick, 2008). It's likely that if Iran does acquire nuclear weapons, several Arab states would withdraw from the Nuclear Non-Proliferation agreement (MacAskill & Traynor, 2003). *The Guardian* reported in 2003 that Saudi Arabia issued a strategic report which suggested that in the event of Iran developing a nuclear weapon, one of the country's options would be to develop its own nuclear weapon as a deterrent and Egypt is reported to have carried out clandestine experiments which could be used for nuclear weapons (Khaitous, 2008). Thus, the potential for nuclear *weapons* in Iran has resulted in an increased interest in *nuclear energy* in the rest of the Middle East indicating that traditional security concerns can be a strong driver to nuclear power development.

4. Clusters of countries and paths of development

This analysis leads to the emergence of four distinct types of Newcomer Countries: 10 countries which are likely to develop nuclear energy, 13 countries where the development of nuclear energy is possible, 14 countries where the development of nuclear energy is unlikely, and 11 countries where the development of nuclear energy is risky. The following sections will discuss possible development pathways for nuclear energy in each type of country and justifications for this classification.

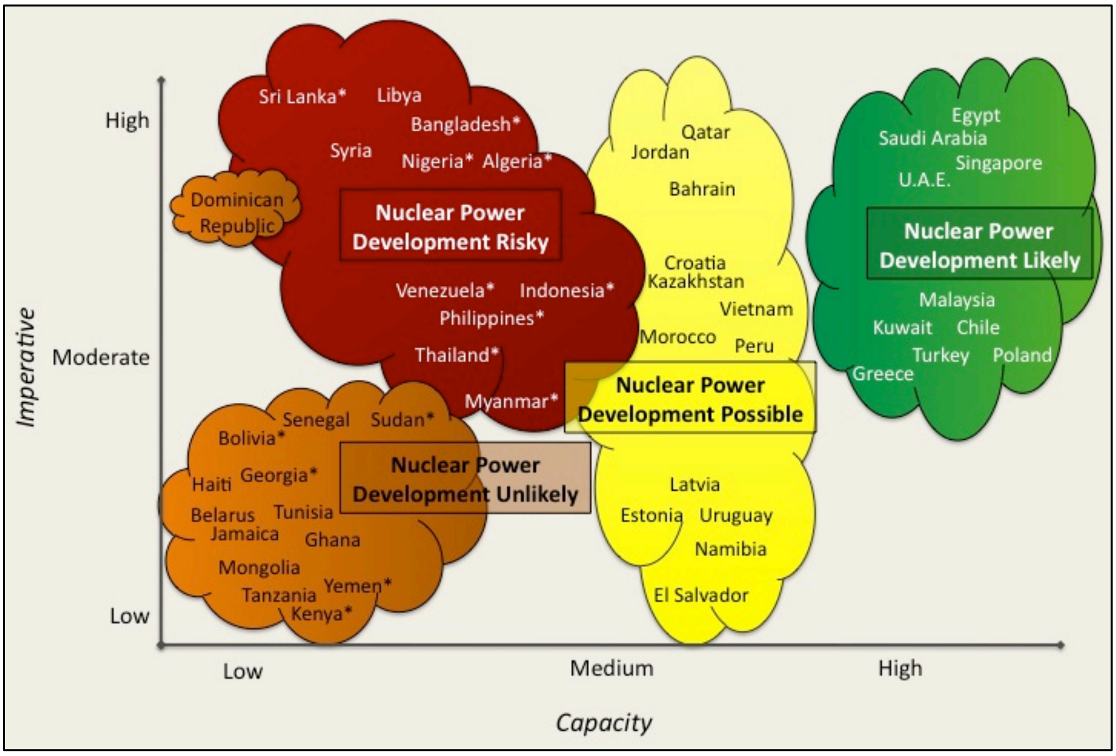

Figure 4 Summary of results from the imperative and capacity frameworks for Newcomer Countries
** Indicates politically unstable states*

4.1.Nuclear power development likely

Only 10 countries are rated as having a high enough capacity and imperative to develop nuclear power in a business-as-usual scenario. This group contains: 4 MENA countries, 3 European countries, 2 Southeast Asian countries, and 1 Latin American country. All of these countries currently have grid capacities which exceed the requisite 10 GWe to accommodate a NPP and high financial capacities with GDPs over 66 billion USD_{2000}.[18] Based on the Government Effectiveness ratings and the comparison with ownership arrangements in Existing Countries, all except Egypt and Saudi Arabia are likely to be able to garner private investment in nuclear energy.

Egypt and Saudi Arabia also stand out from the rest as big players in the shadow of Iran and there is evidence that in the past they have considered the development of nuclear weapons. It is likely that if nuclear energy develops in these countries it will be accompanied by a similar agreement to the one just signed between U.A.E. and the U.S in which the U.A.E. agreed to forfeit the right to enrich and process its own fuel in return for the permission to do business with U.S. nuclear firms (Lakshmanan, 2009).[19]

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[18] All except Kuwait have GDPs above $100 billion USD_{2000}. Although Kuwait's GDP is only 66 billion, as a high income country with a 2007 GDP/capita PPP over $47,000, it is likely that the country could fund and gather financing for a NPP

[19] The deal is the first of its kind and was signed recently by Barack Obama who has hailed the agreement as "a model for the world" (Solomon & Coker, 2009).

4.2. Nuclear power development possible

Another 13 countries are rated as possibly having high enough capacity and imperatives for nuclear power development. These countries have sufficient institutional capacity but are small economies with small grids. In spite of the limited grid size, these countries all have (or will soon have) international grid connections and would thus be able to overcome the grid requirement. Due to their limited financial capacity, one potential nuclear development strategy would be joint implementation with neighboring states. Within this group of countries, there are two sets of countries which are geographically close to each other and thus could potentially institute a joint NPP. This would be a possibility for the Middle Eastern countries (Jordan, Qatar and Bahrain) and for the two Baltic states (Latvia and Estonia). In the Gulf States, with the current construction of the Gulf Interconnection grid, which will include Bahrain, U.A.E., Saudi Arabia, Qatar and Kuwait, the possibility for joint implementation is high. In the Baltic states, with Lithuania as a geographically close Existing Nuclear Country and strong international grid connections, there is also a possibility for cross-country collaboration.

4.3. Nuclear power development risky

In 11 countries nuclear power development is risky. Nine of these states are characterized by political instability (Algeria, Nigeria, Indonesia, the Philippines, Bangladesh, Thailand, Sri lanka and Venezuela) and there is historical evidence that four of these countries have explored or are exploring the development nuclear weapons (Algeria, Syria, Myanmar and Libya). Seven of these countries (Algeria, Bangladesh, Indonesia, Nigeria, the Philippines, Thailand, and Venezuela) have moderate to high financial capacity and these states are the most troublesome because they are likely be able to garner the financial resources to build a national nuclear power program but there is a risk that: they would be unable to safely manage it due to political instability of their countries or the pursuit of nuclear energy would be accompanied by a parallel pursuit of nuclear weapons.

The two politically stable countries in this group (Syria and Libya) historically have had interest in nuclear weapons development. Indicators for national imperatives and capacity demonstrate that in general, countries had GDPs above 50 billion USD_{2000} and were politically stable when they instituted nuclear power. Pakistan is the only country with a GDP below 50 billion USD_{2000} and it is a weapons states. Thus, given these countries' historical interest in nuclear weapons, and their borderline financial capacity, it is possible that the pursuit of nuclear weapons would accompany the development of nuclear energy.

4.4. Nuclear power development unlikely

There are 15 states where nuclear power development is unlikely. Most of these countries are characterized by low imperatives for the development of nuclear power. The Dominican Republic is the only country in this group with a high imperative, however given it's low financial and technical capacity, it is unlikely to successfully implement nuclear energy. These countries are characterized by low financial capacities and small, unconnected grids. Only Tunisia has a Government Effectiveness rating which would indicate it could garner private investment for nuclear power. Given these countries' poor financial and technical capacities for nuclear power development, it is highly unlikely that in lieu of the development of smaller reactors they would be able to develop nuclear power.

The following two sections discuss the results and analysis for the imperatives and capacities for nuclear energy in Existing Nuclear States and Newcomer Countries. In general, the Newcomer Countries show a greater range of both motivational driving forces for pursuing nuclear energy and capacities for successful implementation than the historical and contemporary data for Existing Nuclear States.

5. Concluding remarks

This study aimed to evaluate and characterize Newcomer Countries' imperatives and capacities to develop a nuclear power program. In order to evaluate Newcomer Countries, it reviewed the primary drivers and barriers to nuclear power development and then set up a framework to evaluate a Newcomer Country's imperatives for nuclear energy as well as its capacity to overcome these barriers. The system of indicators includes measures of financial, institutional and technical capacity and was established by comparing the data from indicators for Newcomer Countries to current and historical data from Existing Nuclear Countries. By comparing the data for Newcomer Countries to both historical and current data for Existing Nuclear Countries, it contributes to the understanding of the driving forces and barriers for nuclear energy and the way these driving forces may play themselves out in Newcomer Countries.

While this methodology does offer a contextualized picture of Newcomer Countries, it does suffer from three main limitations. For one, it obviously does not include all factors which influence nuclear power development. Due to the lack of suitable indicators, the following capacity considerations were excluded: human resources, ability to garner international support, ability to establish nuclear waste facilities, geographical suitability, popular support for nuclear energy, and indigenous nuclear facilities. Additionally, this framework excluded imperatives related to local and global pollution as well as indigenous energy sources. The second main limitation is that even though the majority of analysis is based on comparing Newcomer Countries to Existing Countries, historical data cannot offer an exact parable to today since all existing nuclear power programs were set up in state-controlled monopolies and before the end of the cold war. The third major limitation is that this study does not consider the potentially game-changing developments in nuclear energy such as the development of commercially-viable small reactors or the establishment of an international nuclear fuel bank.

In spite of these limitations, the past data from nuclear power development in Existing Nuclear Countries offers wisdom and guidance for the future development of nuclear power in Newcomer Countries. The historical record reveals that political instability, when accompanied by military rule, is a high risk for nuclear weapons pursuits. As a result, eleven countries are rated as risky for nuclear power development due to their political instability and/or nuclear weapons aspirations. The development of nuclear power in unstable countries will not necessarily lead to nuclear weapons development (as evidenced by Argentina's efforts which were thwarted) however, the risk is higher than in stable countries. Combining this research with quantitative characterizations of a country's security concerns could provide guidance to policy-makers about where the pursuit of nuclear energy is safe enough to warrant investment and support. As a multilateral organization, the IAEA maintains that "there are no good and bad countries" in terms of nuclear power (GAO, 2009), however, given the results of this study, it may behoove the international community to develop guidelines of where to support the development of nuclear energy and where to withhold support. While the U.S. Government Accountability Office (2009) recently issued a report with a similar recommendation, this study presents the empirical data to support such a policy as well as a framework to be used to evaluate Newcomer Countries.

One issue that would be useful to add to such an evaluation is an assessment of the compatibility and availability of non-nuclear energy sources in order to fully understand the motivation for nuclear power. In the evaluation of Nuclear Newcomers, fifteen countries were identified as having a low imperative and low capacity to develop nuclear power. Thus the question arises as to what the rationale of these countries is for pursuing nuclear energy. With the lack of the demand imperative, it is not clear why many of these countries want to develop nuclear power. For example, for many of the Sub-Saharan African Newcomers, with low electricity demand which is often dispersed in rural areas, it is not clear why there would be interest in nuclear power over distributed generation which would potentially be more compatible with their needs and capacities. Similarly, it is not clear why the North African countries would pursue nuclear power over installing liquid natural gas lines on the Mediterranean or developing a large-scale solar energy farms with connections to Europe. Untangling these alternatives and the preference for nuclear power will be critical to understanding tacit motivations and ensuring the safe and secure development of nuclear power.

References

Ahmed, S. (1999). Pakistan's Nuclear Weapons Program: Turning Points and Nuclear Choices. *International Security*, *23*(4), 178-204. doi: 10.2307/2539298

Alhajji, A. F., & Williams, J. L. (2003). Measures of petroleum dependence and vulnerability in OECD countries. *Middle East Economic Survey*, *46*, 16.

APERC (Asia Pacific Energy Research Centre). (2007). *A quest for energy security in the 21st century*. Tokyo: Institute of Energy Economics. Retrieved October 6, 2009, from http://www.ieej.or.jp/aperc/2007pdf/2007_Reports/APERC_2007_A_Quest_for_Energy_Security.pdf

Barnaby, F. (2009). *The nuclear renaissance: Nuclear weapons proliferation and terrorism*. London: Institute for Public Policy Research. Retrieved September 21, 2009, from http://www.ippr.org.uk/publicationsandreports/publication.asp?id=650

Bazilian, M., & Roques, F. (2008). *Analytical Methods for Energy Diversity and Security: Portfolio Optimization in the Energy Sector: A Tribute to the work of Dr. Shimon Awerbuch*. Elsevier Science.

Bogomol'nyi, M. (1976). Levels of electric energy production in the USSR. *Power Technology and Engineering (formerly Hydrotechnical Construction)*, *10*(3), 294-296. doi: 10.1007/BF02407380

Bunn, M. (2001). Civilian nuclear energy and nuclear weapons programs: The record. *Cambridge, MA: Belfer Center for Science and International Affairs*.

de Coninck, H. (2008). Trojan horse or horn of plenty? Reflections on allowing CCS in the CDM. *Energy Policy*, *36*(3), 929-936. doi: 10.1016/j.enpol.2007.11.013

Davey, W. G. (1982). *Nuclear power in the Soviet Bloc* (No. LA-9039). Los Alamos, New Mexico: Los Alamos National Laboratory.

Du, Y., & Parsons, J. E. (2009). Update on the Cost of Nuclear Power. *MIT Center for Energy and Environmental Policy Research Working Paper*, 09-003.

EIA. (2009). *Petroleum Navigator*. Washington, DC: US Energy Information Agency. Retrieved March 19, 2009, from http://tonto.eia.doe.gov/dnav/pet/hist/wtotusaw.htm

EIA. (2008). *World Total Electricity Installed Capacity, Most Recent Annual Estimates, January 1, 1980 - January 1, 2007*. Washington, DC: US Energy Information Agency. Retrieved April 27, 2009, from http://www.eia.doe.gov/emeu/international/electricitycapacity.html

Finon, D., & Roques, F. (2008). *Financing arrangements and industrial organisation for new nuclear build in electricity markets* (Cambridge Working Paper in Economics No. EPRG 0826). University of Cambridge. Retrieved from http://www.electricitypolicy.org.uk/pubs/wp/eprg0826.pdf

Fitzpatrick, M. (2008). Will Nuclear Energy Plans in the Middle East Become Nuclear Weapons Strategies? *International Relations*, *22*(3), 381.

Fréchette, L. (2008, September 30). The nuclear option: Is the World ready for a nuclear renaissance? Retrieved September 21, 2009, from http://fletcher.tufts.edu/ierp/pdfs/Frechette_paper.pdf

Fuhrmann, M. (2009). Proliferation and peaceful nuclear cooperation agreements. *International Security*, *34*(1).

GAO. (2009). *Nuclear nonproliferation: Strengthened oversight needed to address proliferation and management challenges in IAEA's technical cooperation program* (Report to the Chairman, Subcommittee on Oversight of Government Management, the Federal Workforce, and the District of Columbia, Committee on Homeland Security and Governemental Affairs, U.S. Senate No. GAO-09-275). Washington, DC: United States Government Accountability Office. Retrieved April 2, 2009, from http://www.gao.gov/new.items/d09275.pdf

Harding, J. (2007). Economics of Nuclear Power and Proliferation Risks in a Carbon-Constrained World. *The Electricity Journal*, *20*(10), 65-76. doi: 10.1016/j.tej.2007.10.012

Hudson. (1982). *Hungary finally comissions its first nuclear reactor* (No. 37-7-240). Budapest: OSA. Retrieved May 19, 2009, from http://www.osaarchivum.org/files/holdings/300/8/3/text_da/36-7-240.shtml

IAEA. (2008a). *Financing of new nuclear power plants* (Technical Report No. No. NG-T-4.2). Nuclear Energy Series. Vienna: IAEA.

IAEA. (2008b). Personal Communication with H.H. Rogner.

IAEA. (2007a). *Considerations to launch a nuclear power programme*. Vienna: IAEA. Retrieved March 10, 2009, from http://www.iaea.org/NuclearPower/Downloads/Launch_NPP/07-11471_Launch_NPP.pdf

IAEA. (2007b). *Milestones in the development of a national infrastructure for nuclear power* (Guide No. NG-G-3.1). Nuclear Energy Series. Vienna: IAEA. Retrieved January 8, 2009, from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1305_web.pdf

IAEA. (2008). *Evaluation of the status of national nuclear infrastructure development* (Technical Report No. NG-T-3.2). Nuclear Energy Series. Vienna: IAEA. Retrieved from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1358_web.pdf

IAEA. (2009, March 9). Nuclear Power Plants Information. *Power Reactor Information System*. Retrieved March 8, 2009, from http://www.iaea.org/programmes/a2/

IEA. (2008). *World Energy Outlook 2008*. Paris: OECD.

IEA. (2009a). Balances. *International Energy Agency: Statistics*. Retrieved April 25, 2009, from http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Balances

IEA. (2009b). Electricity/Heat Statistics. *Inernational Energy Agency: Statistics*. Retrieved April 22, 2009, from http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Electricity/Heat

IEA. (2009c). Energy Security. *International Energy Agency: Energy Security*. Retrieved March 26, 2009, from http://www.iea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4103

IPCC. (2007). Summary for Policy Makers. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, et al. (Eds.), *Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Jansen, J. C., Van Arkel, W. G., & Boots, M. G. (2004). *Designing indicators of long-term energy supply security.* Energy research Centre of the Netherlands ECN; ECN Knowledge Agency [distr.].

Jones, R. W., McDonough, M. G., & Spector, L. S. (1998). *Tracking nuclear proliferation.* Carnegie Endowment for International Peace.

Kaufmann, D., Kraay, A., & Mastruzzi, M. (2008). *Governance matters VII: Aggregate and individual governance indicators 1996-2007* (Policy Resarch Working Paper 4654 No. WPS4654). Washington, DC: World Bank. Retrieved February 3, 2009, from http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2008/06/24/000158349_20080624113458/Rendered/PDF/wps4654.pdf

Kåberger, T. (2007). History of nuclear power in Sweden. *Estudos Avançados*, *21*(59), 225-242.

Khaitous, T. (2008, May 23). Why Arab leaders worry about Iran's nuclear program. *Bulletin of Atomic Scientists*. Retrieved May 20, 2009, from http://www.thebulletin.org/web-edition/features/why-arab-leaders-worry-about-irans-nuclear-program

KK. (1974). *Initial production capacity of Hungarian atomic power plant to be doubled* (No. 35-5-212). Budapest: Radio Free Europe. Retrieved May 19, 2009, from http://www.osaarchivum.org/files/holdings/300/8/3/text_da/35-5-212.shtml

Kristensen, H. M., & Godsberg, A. (n.d.). *Romania special weapons*. Retrieved from http://www.fas.org/nuke/guide/romania/index.html

Lakshmanan, I. A. (2009, February 3). A model nuclear-power deal? *The International Herald Tribune*. Retrieved March 13, 2009, from http://www.iht.com/articles/2009/02/03/mideast/letter.1-421715.php

Laurence, W. L. (1955, August 6). Nuclear history due to be made in geneva parley. *New York Times*.

Lindregen, M. (2009). *GDP per capita by purchasing power parities* (No. Gapminder Documentation 001-Version 5). Gapminder.org. Retrieved May 16, 2009, from http://www.gapminder.org/gapminder-world/documentation/

Lovins, A. B., Sheikh, I., & Markevich, A. (2009). Nuclear power: Climate fix or folly. *Rocky Mountain Institute*. Retrieved from http://www.rmi.org/cms/Download.aspx?id=1138&file=E09-01_NuclPwrClimFixFolly1i09.pdf

MacAskill, E., & Traynor, I. (2003, September 18). Saudis consider nuclear bomb. *The Guardian*. Retrieved May 20, 2009, from http://www.guardian.co.uk/world/2003/sep/18/nuclear.saudiarabia

Macfarlane, A. M., & Miller, M. (2007). Nuclear Energy and Uranium Resources. *ELEMENTS*, *3*(3), 185-192. doi: 10.2113/gselements.3.3.185

Maddison, A. (1995). *Monitoring the World Economy, 1820-1992*. Development Centre of Organisation and Develo.

Maddison, A. (2003). *The World Economy*. Paris: OECD.

Martin, D. (1996). *Exporting disaster: the cost of selling CANDU reactors*. Canadian coalition for nuclear responsibility. Retrieved from http://www.ccnr.org/exports_1.html

Montgomery, A. H., & Sagan, S. D. (2009). The Perils of Predicting Proliferation. *Journal of Conflict Resolution*, *53*(2), 302.

National Academy of Sciences (U.S.). U.S. Committee on the Internationalization of the Civilian Nuclear Fuel Cycle, Committee on International Security and Arms Control, Policy and Global Affairs, National Academy Of Sciences, & National Research Council. (2008). *Internationalization of the Nuclear Fuel Cycle*. National Academies Press.

NEA. (2008). *Nuclear Energy Outlook* (No. No. 6348). Paris: OECD.

Nizamani, H. K. (2000). *The roots of rhetoric: politics of nuclear weapons in India and Pakistan*. Greenwood Publishing Group.

NTI. (2009, October). Country Overviews: India: Nuclear Overview. *Nuclear Threat Initiative*. Retrieved November 14, 2009, from http://www.nti.org/e_research/profiles/India/Nuclear/index.html

NTI. (2008). *Syria Profile* (Nuclear Overview). Washington, DC: Nuclear Threat Initiative. Retrieved June 14, 2009, from http://www.nti.org/e_research/profiles/Syria/Nuclear/index.html

NTI. (2009, August 3). NTI: Global Security Newswire - Myanmar Wants Nuclear Weapons, Defectors Say. *Nuclear Threat Initiative*. Retrieved November 15, 2009, from http://www.globalsecuritynewswire.org/gsn/nw_20090803_6611.php

Nuttall, W. (2004). *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power* (1st ed.). Taylor & Francis.

Nuttall, W., & Taylor, S. (2008). *Financing the Nuclear Renaissance* (Cambridge Working Paper in Economics No. EPRG 0814). University of Cambridge. Retrieved March 9, 2009, from http://www.electricitypolicy.org.uk/pubs/wp/eprg0814.pdf

Pacala, S., & Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, *305*(5686), 968-972.

Parenti, C. (2008, April 24). What nuclear renaissance? *The Nation*.

PITF. (2008). *Historical state armed conflicts and regime crises, 1955-2007* (Political Instability Task Force). Center for Systemic Peace. Retrieved from http://www.systemicpeace.org/inscr/PITFConsolidatedCaseList2007.pdf

Puig, A. P. I. (2005). Science on the Periphery. The spanish Reception of Nuclear Energy: an Attempt at Modernity? *Minerva (London)*, *43*(2), 197-218.

Röller, L. H., Delgado, J., & Friederiszick, H. W. (2007). *Energy: choices for Europe*. Bruegel Blueprint Series. Brussels: Bruegel.

Sagan, S. D. (2000). Rethinking the causes of nuclear proliferation: Three models in search of a bomb. *The coming crisis: Nuclear proliferation, US interests, and world order*.

Sahr, R. C. (2009). *Consumer price index (CPI) conversion factors 1774 to estimated 2019 to convert to dollars of 2008* (No. Revised 04/01/2008). Corvallis, Oregon: Oregon State University. Retrieved from http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2008.pdf

Sauga, M. (2008, July 11). The atomic age enters a new dawn. *Spiegel Online International*. Retrieved March 2, 2009, from http://www.spiegel.de/international/world/0,1518,565132,00.html

Scheepers, M., Seebregts, A., de Jong, J., & Maters, H. (2007). *EU standards for energy security of supply*. Petten, Netherlands: ECN/Cligendahl International Energy Programme.

Scheepers, M., Seebregts, A. J., de Jong, J., & Maters, H. (2006). *EU standards for energy security of supply*. Petten, Netherlands: ECN/Cligendahl International Energy Programme.

Schneider, M. (2008). 2008 world nuclear industry status report: Global nuclear power. *Bulletin of Atomic Scientists*. Retrieved March 9, 2009, from http://www.thebulletin.org/web-edition/reports/2008-world-nuclear-industry-status-report/2008-world-nuclear-industry-status-rep

Shannon, C. E., & Weaver, W. (1963). *The Mathematical Theory of Communication*. Urbana, IL: University of Illinois Press.
Sims, R. E., Scho, R. N., Adegbululgbe, A., Fenhann, J., Konstantinaviciute, I., Moomaw, W., et al. (2007). Energy Supply. In B. Metz, O. Davidson, P. Bosch, & L. Meyer (Eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
Singh, S., & Way, C. R. (2004). The correlates of nuclear proliferation: A quantitative test. *Journal of Conflict Resolution*, *48*(6), 859.
Socor, V. (1985). *Soviet-Romanian programs in nuclear energy development* (No. 53-7-16). Radio Free Europe. Retrieved May 19, 2009, from http://www.osaarchivum.org/files/holdings/300/8/3/text_da/53-7-16.shtml
Solomon, J., & Coker, M. (2009, April 2). Oil-Rich Arab state pushes nuclear bid with U.S. help. *Wall Street Jornal Online*. Retrieved May 24, 2009, from http://online.wsj.com/article/SB123862439816779973.html
Sovacool, B. K. (2008). Valuing the greenhouse gas emissions from nuclear power: A critical survey. *Energy Policy*, *36*(8), 2940-2953.
Stirling, A. (1994). Diversity and ignorance in electricity supply investment: Addressing the solution rather than the problem. *Energy Policy*, *22*(3), 195-216.
Stirling, A. (1998). On the economics and analysis of diversity. *Science Policy Research Unit (SPRU), Electronic Working Papers Series, Paper*, *28*.
Toth, F. L. (2008). Prospects for nuclear power in the 21st century: a world tour. *International Journal of Global Energy Issues*, *30*(1-4), 3.
Walker, M. (1992). *German National Socialism and the Quest for Nuclear Power, 1939-49*.
Wolfe, J. (2007, November 14). Nuclear Renaissance. *Forbes*.
World Bank. (2009). *World Development Indicators Online*. The World Bank Group. Retrieved April 29, 2009, from http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=6
Yergin, D. (2006). Ensuring Energy Security. *Foreign Affairs*, *85*(2), 69-82.

Appendices available at: http://spreadsheets.google.com/ccc?key=0ArGXGFE04vHsdDE1QkpBVm1OZk9salkxS05ENkhFbGc&hl=en