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Exploring the Viability of Investment in Small Modular Nuclear Reactors (SMRs): Mitigating Climate Change through Advancements in Energy Generation

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Abstract

Under the Paris Agreement, the international community established a goal: keeping the global mean temperature rise below 2°C to mitigate climate change. Accomplishing this will require significant reductions of greenhouse gases emissions (GHGs) by 2050 through economic, social, and infrastructure improvements. For the latter, one of the significant avenues for change is the possible development of small modular nuclear reactors (SMRs). These new advanced-type nuclear reactors are built in modular arrangements of less than 300 megawatts (MW) and are expected to resolve the major issues with traditional nuclear plants through improvements in up-front capital cost, efficiency, and safety standards. This paper explores the viability of SMRs as a reliable and carbon-free addition to baseload energy generation through analyses of six comparable SMR projects potentially implemented in 22 countries. We conducted cost-benefit analyses under different assumptions of discount rates (%) and electricity prices (USD/MWh) to find the economic viability of SMRs under current and possible market conditions and determined 'breakeven' prices and discount rates that would make the investments profitable. Results are reported by country and as world averages. Out of the 138 potential projects worldwide, we identified favorable investment conditions for 66 projects (47.8%) under a flat assumption of a 4% discount rate, which increases to 82 projects (59.4%) when discount rates vary by country. For example, the United States qualifies for four out of six SMR projects at a discount rate of 4% while qualifying for all six at a discount rate of 0.25%. Overall, we found that for 14 out of 22 analyzed countries (63.6%), including the United States, an investment in SMRs could be profitable and beneficial, serving as a sign that countries should consider implementing this technology.

Introduction

Keeping the global mean temperature rise below 2°C as established in the Paris Agreement will require significant reductions of worldwide greenhouse gases emissions (GHGs) by 2050. Reductions of this magnitude will require large economic, social, and infrastructure development across the world.

President Biden's recent rejoining of the agreement means that many avenues for change will present itself in the United States. Currently, the energy production sector accounts for 27% of GHGs, just trailing the largest segment, transportation, at 28% (1). In the energy sector, 63% of GHGs come directly from burning fossil fuels (1). Therefore, it stands to reason that making changes in the energy production sector will be necessary to significantly reduce GHGs by 2050.

Background

There are two main categories of electricity generation: baseload and peak load. Due to the current technological inability to store electricity on a large scale, energy generation must meet energy demand at the time it is demanded. Peak load generation is used to meet peaks of daily electricity demand, while baseload operates continuously. Historically, coal and nuclear plants comprised the baseload generation and produced the most energy while natural gas combined cycle plants (NGCCs) have been used for peaks. Renewables sources of energy like solar and wind have offset reliance on fossil fuels but because their inherent intermittency, they cannot reliably function in either category.

While closures of coal plants have been occurring over the last decade, new investment in low-GHG baseload generation is lacking. From 2019-2020, natural gas power generation increased by 9% while nuclear power generation decreased by 4% (2). This trend is projected to continue due to an increase in dry natural gas supply that has pushed natural gas prices to historic lows. Prices in June of 2020 reached a low of $1.63 per million British thermal units (MMBtu), the lowest monthly inflation-adjusted price since 1989. Natural gas prices in the U.S. have remained low due to an increase in dry natural gas production, a decline in exporting liquefied natural gas, and warmer than normal winters. The growth in natural gas power generation this past year is not an exception, and the low price of natural gas will continue to encourage more natural gas consumption in the electric power sector (3). While natural gas units have historically been used for peak loads, this trend of sustained low natural gas prices and the operational flexibility have enabled them to be used for baseload power, potentially increasing our reliance on fossil fuels. According to scholars, "nuclear power is the only baseload electricity source that could effectively replace fossil-burning plants and help in reduction of global warming threat" and is already reducing GHGs by "2.5 billion tons per year" (4).

Further examination of current trends shows that "U.S. nuclear power generating capacity is projected to decline from 99.3 gigawatts (GW) to 79.1 GW over the period of 2017-50", a decrease of 20.3% (5). In fact, six nuclear plants are projected to be closed by 2025, and, other than Watts Bar Unit 2 in the Tennessee Valley region, there have been no new additions to the U.S. nuclear fleet since 1996 (5). This trend of large nuclear reactor closures and lack of new investment will only be exacerbated over the years due to large upfront capital costs, perceived risk, perception, and comparatively low costs from other forms of energy generation. Additionally, when nuclear plants begin operation, they receive licenses from the Nuclear Regulatory Committee (NRC) to operate for 40 years. After this term expires, plants have been able to receive a renewal for an additional 20 years (6). As of now, there is no precedent for a second renewal, and therefore, a huge wave of nuclear plants maybe be retiring over the course of 2030 – 2050 when their licenses run out.

One of the largest concerns about nuclear energy involves impacts from adverse events including damages, health impacts, and even deaths. As of now, there have been approximately 30 reported adverse events globally since the introduction of the first nuclear reactor on the grid in 1951 (7). Out of these reported events, the impact varies greatly. The two most infamous are the Chernobyl nuclear disaster in former Ukrainian SSR in 1986 and the Fukushima Daiichi nuclear disaster in Japan in 2011. While the causes of both disasters and their ensuing impacts vary, they have had the largest known and predicted impact on human life. In the case of Chernobyl, death estimates from radioactive fallout and the ensuing cancer diagnosis vary. A more pessimistic estimation lands at 14,000 deaths up to 2065 as estimated by a group of experts through calculating radiation doses, estimating cancer risk projections, and applying trends in cancer mortality (8). A lower estimate comes from the World Health Organization (WHO) which states that "the total number of people that could have died or could die in the future due to Chernobyl originated exposure over the lifetime of emergency workers and residents of most contaminated areas is estimated to be around 4,000" (9). Fukushima, the second-largest disaster, saw a total of 573 direct deaths from the accident, mainly from evacuation stress (10). Radiation related deaths on the other hand, have been estimated at around 1000 (11). Other adverse events have caused deaths, but none come close to these disasters.

Comparatively, these numbers are dwarfed by deaths caused by fossil fuels. As mentioned above, fossil fuels have been cited as the leading cause of environmental related deaths due to the release of both ambient air particles and fine particle pollution, both of which are carcinogens (12). In fact, the WHO has estimated that ambient air pollution is the cause of deaths/disease of 43% of COPD, 29% of lung cancer, 25% of ischemic heart disease, and 24% of stroke (13). These add up, leading to over 132 million deaths caused by indoor and outdoor air pollution from 1990 to 2017 (14). While this is true, it can be argued that because fossil fuels generate a larger portion of the electric generation mix, as mentioned above, these numbers are not comparable to the raw death totals from adverse nuclear events. Therefore, as opposed to comparing totals, it would be more effective to examine death rates per an energy unit, such as terawatt hour (TWh). Using this metric, the annual death rate from accidents and air pollution are as follows: 24.6 deaths for coal, 18.4 deaths for oil, 2.8 deaths for natural gas, and 0.07 deaths for nuclear energy (15). In summary, that would equate to 1 death every 14 years due to nuclear energy generation, and 641 deaths for fossil fuels over that same time span. Regardless of the metric, it is evident that there seems to be lower death rates due to nuclear when compared to fossil fuels.

Regarding direct environmental impact, nuclear power has been a topic of conversation for many years. Scholars show that both the nuclear power industry and the coal industry will, for now, remain as mainstays in the energy production industry in the United States of America (4). When compared to coal energy, nuclear energy has led to fewer deaths, near zero pollution effects (excluding nuclear waste), and can sustainably meet future energy needs. In fact, nuclear power is unique in its position in the discussion over climate change due to its position as a carbon-free energy source that "is already contributing to world energy supplies on a large scale, has potential to be expanded if the challenges of safety, nonproliferation, waste management, and economic competitiveness are addressed, and is technologically fully mature" (16). This is significant in proving that utilizing nuclear energy is a successful method to offset environmental impacts.

SMR Technology vs. Traditional Large Nuclear Reactors

SMRs are an advanced type of nuclear reactor built in modular arrangements of less than 600MW and shipped to the end location (16). They are expected to resolve the major issues with traditional nuclear plants including improvements in up-front capital cost, efficiency, and safety standards. As of now, SMR designs are in varying stages, including some in the process of licensing and some that are under construction, but there are only several are in operation in Russia. As of August 28th, 2020, during the course of this study, the U.S. Nuclear Regulatory Commission (NRC) officially approved the design and construction of NuScale's 12-module power plant (17). At current construction estimates, NuScale plans to be able to deliver its first SMR module to customers by 2027 (18).

According to experts (19), economic rationales for investment in SMRs include:

- Modularity, which allows for a cost-effective, staggered construction cycle marked by reducing up-front investment cost, incorporating positive cash flows during the construction period, reducing labor-related costs, better controlling construction time (which has been known to go over for traditional reactors) and providing buffer for uncertainty in future electricity prices thereby reducing risk and financial burden,
- Flexible output designs that allow SMRs to ramp up generation to respond to variation in renewable outputs,
- Improved energy security due to nuclear power not being affected by changes in commodity markets like oil and gas,
- Increased access to a wider range of markets, including remote locations, due to their "small size and inherent safety features",

- Passive safety features reducing/eliminating the risk of fuel damage and radiation release,
- Smaller fuel inventory reducing "maximum possible release during an adverse event",
- Standardized off-site construction of modules creating cost savings compared to site-specific deployment of large nuclear reactors,
- The possibility of an 'early mover advantage' for the U.S. which could become a world industry leader in SMRs, like Denmark with wind energy, creating employment opportunities and increasing their position in the global market.

Compared to large nuclear reactors, SMRs can "better match demand growth at lower up-front capital costs, provide flexibility to integrate with renewables and repower retired fossil plant sites, and can generate resilient baseload power" (20), Therefore, SMRs can beat out large nuclear reactors through their modularity, lower capital investment, higher efficiency, and better safety standards. In fact, according to an analysis conducted by the Organization for Economic Co-operation and Development (OECD), "SMRs could be competitive with many non-nuclear technologies in the cases when [nuclear power plants] with large reactors are unable to compete" (21). While this is the case, relatively few dollars are spent investing in SMR technology as opposed to investing in NGCCs, as mentioned above.

SMRs and Emission Abatement

Regarding the effect on the carbon emissions, Iyer et al. discuss the viability of SMRs in reducing the effects of climate change. Utilizing the Global Change Assessment Model (GCAM), a dynamic-recursive model, the authors inputted prices under different assumptions of SMR costs and availability of large reactors to determine GHG emissions. Under this model, it was shown that net present value of abatement costs can be reduced by upwards of 27% with high-tech SMRs if there is no market competition from large nuclear reactors (19). The decrease in abatement costs tapers off with assumptions of lower tech SMRs or with the assumption of large nuclear reactors as a market competitor. Given the constant decline of traditional nuclear highlighted at the beginning of the paper, this market competition seems unlikely, meaning the introduction of SMRs will lower abatement costs by 3% to 27%. The authors emphasize that "even pessimistic assumptions about SMR tech and costs can lead to a reduction in mitigation costs" and that regardless of assumptions, "the costs of achieving a 2 °C target are lower with SMRs than without" (19). Therefore, effective implementation of SMRs is expected to lower the costs of keeping global mean temperature rise below 2 °C, the goal agreed upon in the Paris Climate Agreement.

Challenges to SMR Investment

These advantages are marked by challenges with both investor perception of risk due to upfront capital cost and public perceptions of traditional nuclear power (19). While this is the case, the lower capital costs, inherent safety of SMRs, and incumbent regulations on nuclear power will help mitigate these costs. Certain concerns, including waste disposal, terrorism, proliferation of nuclear weapons, and adverse events, are not entirely answered by SMR technology.

In addition to the challenges normally faced by nuclear power generation, SMRs present several new challenges (19):

- Lock-in effects cause both utility companies and regulatory frameworks to have bias toward incumbent technologies,

- Restrictions due to current nuclear licensing in the US may impede adoption, such as not allowing control of two reactors from the same operating room,
- Differences in international regulatory processes may affect the diffusion of SMR technology,
- Lack of information for new technologies creates uncertainties which could adversely affect SMRs, which may struggle with public perception anyways,
- An inability to reach economies of scale.

For context, economies of scale are the cost advantages that arise when ramping up production due to more efficient means of production; they have been a key driver of traditional large nuclear reactor construction as seen by a constant trend in increasing output size (reaching upwards of 1600 MW) (22). While SMRs may not reach economies of scale, some experts believe that modularization, less potential for project time/cost overrun, design simplification, and fractioning of total investments into multiple smaller payments may mitigate this cost or counteract it - summarized by the term “Economies of the Multiple” (22).

Methodology

To properly capture the financial viability of SMRs, we conducted cost-benefit analyses to ascertain whether a project would have a positive net present value (NPV) of net benefits (NB). Our process went as follows:

- Calculated benefits over 60 years, the operational lifespan of an SMR (21),
- Calculated costs, including upfront construction costs and yearly costs over 60 years,
- Subtracted costs from benefits to find net benefits per year,
- Calculated the NPV of net benefits by discounting the results by a discount rate,
- Found the breakeven electricity price, the electricity price that makes NPV of NB equal to 0,
- Found the breakeven discount rate, the discount rate that makes NPV of NB equal to 0.

More succinctly, the formula we used to calculate the net present value of net benefits is as follows:

$$NPV_p = \sum_{t=0}^{CS} \frac{\left(\frac{LCOE_p \times PUO_p \times LS_p \times IF_p}{CS_p}\right)}{(1+r)^t} + \sum_{t=CS}^{LS} \frac{\left(EP \times PUO_p\right) - \left(\frac{LCOE_p \times PUO_p \times LS_p \times (1 - IF_p)}{(LS_p - CS_p)}\right)}{(1+r)^t}$$

which can be simplified to…

$$NPV_p = \sum_{t=0}^{CS} \frac{UC_p}{(1+r)^t} + \sum_{t=CS}^{LS} \frac{(R_p - AC_p)}{(1+r)^t}$$

PUO_p is per unit output, LS_p is projected lifespan, IF_p is investment (upfront) component of cost, CS_p is construction time, UC_p is upfront costs, B_p is annual revenue, and AC_p is annual costs. The *p* subscript refers to each individual project *p*. EP is the electricity price, *r* is the discount rate, and *t* is the year *t*.

Any project with positive NPV of net benefits could be argued to be invested in as it is expected to provide a positive return to an investor. These analyses were conducted for six potential SMR reactor projects at module level, under different assumptions of discount rates, and for electricity prices of 23 countries and a world average. Each of the six reactors represents a potential SMR that could be developed for widespread use. Their defining characteristics can be found in Table 1.

Individual Project Characteristics

Project Name	Reactor Output: MWe	Project Output: MWe	Project Output: MWh	Capacity Factor
Project 1: PWR-90(1) single module plant	90	90	709,560	90%
Project 2: PWR-90(2) single module plant	90	90	709,560	90%
Project 3: PWR-125 five module plant	125	625	985,500	90%
Project 4: PWR-302 twin-unit land-based	302	604	2,433,878	92%
Project 5: PWR-335 two twin-units	335	1,340	2,817,216	96%
Project 6: UK SMR Estimation	300	300	2,417,760	92%

MW: Megawatts, equivalent to 1 million watts, or 1000 kilowatts (kW)
MWe: Megawatts electric, the electrical power produced by a reactor (a fraction of total power)
MWh: Megawatt hours, electricity provided over an hour
Capacity Factor: percentage of time a reactor is producing electricity

Table 1: Individual Project Characteristics

Each project is inspired by different projects. Projects 1 & 2 are inspired by SMART Korea, with cost estimates conducted by different firms. They therefore present an example of cost differences due to different estimations. Projects 3 – 6 are inspired by the following, respectively: mPower USA, VBER-300 Russia, IRIS USA, and a UK aggregate example (21).

Our analyses provide breakeven prices and breakeven discount rates for each project in each country. These are the prices or rates that, if achieved, would push the investments into profitable ones. While these calculations require many assumptions that are open to argument/change, we discuss three major economic components: costs, benefits, and discount factors.

Costs:

In general, finding costs of electricity generation is possible through either an analysis of available engineering reports, or by using cost estimates from energy companies. In this case, SMR information is difficult to find, especially in a format that lends itself to an annual basis for discounting purposes. To combat that, we analyzed several techno-economic analyses (TEAs) and found levelized cost of electricity (LCOE) information for each project. The LCOE is an estimate of the revenue required to build and operate a generator over a specified cost recovery period, such as a plant's operating lifetime (23). This estimate gives a summarized, annualized cost required to build a generator including inputs such as fuel, operation & maintenance, and upfront construction cost. Because LCOE estimates include upfront costs and annualize them over time, we separated this portion of the LCOE (52.6%) and then reincorporated it over only the first 3 years (the projected construction time of an SMR). This would allow the cost estimates to have a more realistic weight for earlier years, during the construction period. Using this information, we were able to find annual cost estimates by multiplying the LCOE by a given capacity factor and by per unit MWh output.

Benefits:

Benefits are more difficult to find. Direct benefits from power plants are usually summarized by electricity revenues from generation. Seeing as nuclear power traditionally serves as baseload generation due to the difficult in ramping electricity production up and down, we have confidence that the predicted capacity factor will be accurate. Therefore, to find electricity revenues, we multiplied the per module output in MWh by the capacity factor and by given electricity prices ($/MWh). We began to accrue benefits in year 3, after the prediction construction was completed. There is a precedent to include benefits such as offset cost from the increased loss of human life that would have occurred if a coal plant or similar fossil fuel was built instead. We did not include these in our benefit calculations.

Discount Factor:

We conducted sets of analyses under different discount rate assumptions: 4%, 10%, and country-specific discount rates. We utilized a 4% rate because of its proximity to the world average discount rate, 3.87%. In addition, there is precedent to use a discount rate of this level as seen in analyses conducted by both the OCED and the IEA (21). The 10% analysis was conducted to capture more risk-averse investors, as a higher discount rate would coincide with higher risk, more short-term investing, or with businesses in general as they may be able to receive a higher rate of return investing in other projects. It is important to note that there is a sense of risk associated with nuclear technology impacts on health and safety as mentioned above that may make higher discount rates more applicable. Even though this is the case, the financial modularity of SMRs that allows revenue to be earned much quicker than traditional nuclear power plants should lower the comparative rate. Finally, we looked at the central bank rates within each country and used each of these rates in the calculations for the respective country. These are the rates a nation's central bank offers when loaning to domestic banks. In certain cases, this rate is lower than the rate available to companies potentially investing in SMRs. Even so, we believe that using both a country-specific discount rate and a country-specific electricity price would more accurately reflect the macroeconomic conditions and risk perceptions of the country itself.

Data

The main pieces of data that were collected for this study are individual proposed SMR LCOE data, construction time/cost, SMR project-specific capacity factor, country-specific electricity prices, and country-specific discount rates.

Individual Proposed SMR Projects – LCOE Data

This study conducted analyses on 6 different proposed SMR designs, based on real designs, labelled as Projects 1 through 6. Descriptions and LCOE estimations of Projects 1-5 were obtained from the OECD's Nuclear Energy Agency report on the current status and feasibility of nuclear reactors (21). Project 6 was sourced from United Kingdom's Department of Energy & Climate Change SMR TEA to provide an additional, international cost estimation (24). All monetary values were converted to USD. Additional projects and TEAs from other countries and regions were analyzed, but we were unable to find complete cost information through these sources.

Construction Time and Portion of Levelized Cost

As of now, there is one SMR design approved for construction in the United States – NuScale's 12-module reactor (17). According to their estimates, and other expert estimates, construction time of a SMR module is planned to be 3 years (18). We used this estimation in our treatment of upfront construction costs. In addition, the OECD estimated that 52.6% of the LCOE estimate was due to construction costs (21). We used this percentage to separate upfront costs and spread them across the first three years to better estimate the cost burden.

Capacity Factor

Most proposed SMR projects had estimated capacity factors provided in their project description. Where this information was not readily available (Project 6) we used a capacity factor of 92% as reported by the U.S. Department of Energy (25). Capacity factors for each SMR project are shown in Table 1.

Country-Specific Electricity Prices

A major source of electricity prices by country comes from the International Energy Agency (IEA). Most data points are behind a pay wall, for which we were unable to pay for in this study. However, we were able to use publicly available data found on IEA's website (26). These comprised of residential electricity prices from 2018 in 22 countries, including the United States, and a world average for a total of 23 electricity prices. All monetary values were converted to USD. These countries represent a mix of geographical, cultural, and economic conditions with notable exclusions from North and Central Africa. Electricity prices ranged from $48.00 - $357.90, the highest residential electricity price in 2018.

Country-Specific Discount Rates

Data on each country's discount rate was obtained from the Trading Economics' website (27). These rates coincide with each individual nation's central bank rate as of March 2021. No discrepancies were found when data were compared to the Federal Reserve Economic Data database (FRED) maintained by the Federal Reserve Bank of St. Louis. Discount rates ranged from negative rates in the case of Japan and Denmark up to 38.0% in the case of Argentina. The world average discount rate was calculated across the 22 countries and equals 3.72%.

Results

Several sets of analyses were completed in this project with the following results: summarized results, 4% discount rate assumption results, 10% discount rate assumption results, country-specific results, country-specific breakeven prices/rates.

Summarized Results

Overall, we found that for 14 out of 22 analyzed countries (63.6%), including the United States, an investment in SMRs could be profitable and beneficial. Additionally, out of 414 conducted analyses, spanning the 3 discount rate assumptions, 171 (41.3%) proved to be profitable. Results are summarized in Table 2.

Number of Projects with Postive Net Present Value of Net Benefits

Country	Electricity Price: (USD/MWh)	Country-Specific Discount Rate	4% Discount Rate	10% Discount Rate
Saudi Arabia	$ 48.00	0	0	0
Russia	$ 61.00	0	0	0
Mexico	$ 63.00	0	0	0
India	$ 66.00	0	0	0
Indonesia	$ 77.00	0	0	0
China	$ 81.00	0	0	0
Argentina	$ 95.00	0	0	0
Turkey	$ 104.00	0	0	0
South Africa	$ 109.00	4	2	0
Korea	$ 110.00	5	2	0
Canada	$ 113.00	5	2	0
United States	$ 129.00	5	4	0
Singapore	$ 182.00	6	5	0
Brazil	$ 196.00	5	5	0
France	$ 202.00	6	5	0
Netherlands	$ 211.00	6	5	0
United Kingdom	$ 229.00	6	5	2
Japan	$ 239.00	6	5	3
Australia	$ 248.00	6	5	4
Italy	$ 280.00	6	5	4
Germany	$ 353.00	6	6	5
Denmark	$ 357.90	6	6	5
World Average	***$ 133.70***	**4**	**4**	**0**
Total		**82**	**66**	**23**
Percentages (out of 138 projects)		*59%*	*48%*	*17%*

Table 2: Number of Projects with Positive NPV of NB

As electricity prices increase, the financial viability of SMRs becomes more certain as more projects become viable. As analyses moves from the 10% discount rate to the 4% discount rate to the country-specific rate, more projects become viable as well. This can be explained by the fact that, in general, central bank rates tend to be less than both 4% and 10%. There seems to be relation between viability and the relative democracy of the nation.

4% Discount Rate Assumption

Our first set of analyses utilizes a 4% discount rate due to its proximity to the world average discount rate of 3.87%. In addition, there is a precedent in using a discount rate of this level as seen in analyses conducted by both the OCED and the IEA (21). Our results are presented in Table 3.

Net Present Value of Net Benefits
Under Different Project Assumptions (4% Discount Rate)

Country	Electricity Price: (USD/MWh)	Project 1: PWR-90(1) single module plant	Project 2: PWR-90(2) single module plant	Project 3: PWR-125 five module plant	Project 4: PWR-302 twin-unit land-based	Project 5: PWR-335 two twin-units	Project 6: UK SMR Estimation
Saudi Arabia	$ 48.00	$ (895,711,421.90)	$ (957,326,955.74)	$(2,142,603,510.08)	$ (2,861,051,870.84)	$ (4,045,579,069.77)	$(12,394,794,310.02)
Russia	$ 61.00	$ (704,423,881.18)	$ (766,039,415.03)	$(1,876,926,370.20)	$ (2,204,911,990.43)	$ (3,286,096,685.89)	$(11,742,999,726.83)
Mexico	$ 63.00	$ (674,995,028.77)	$ (736,610,562.61)	$(1,836,052,964.06)	$ (2,103,967,393.44)	$ (3,169,253,242.21)	$(11,642,723,637.11)
India	$ 66.00	$ (630,851,750.14)	$ (692,467,283.98)	$(1,774,742,854.86)	$ (1,952,550,497.97)	$ (2,993,988,076.70)	$(11,492,309,502.53)
Indonesia	$ 77.00	$ (468,993,061.84)	$ (530,608,595.68)	$(1,549,939,121.11)	$ (1,397,355,214.55)	$ (2,351,349,136.49)	$(10,940,791,009.07)
China	$ 81.00	$ (410,135,357.00)	$ (471,750,890.85)	$(1,468,192,308.83)	$ (1,195,466,020.58)	$ (2,117,662,249.14)	$(10,740,238,829.62)
Argentina	$ 95.00	$ (204,133,390.08)	$ (265,748,923.92)	$(1,182,078,465.88)	$ (488,853,841.68)	$ (1,299,758,143.42)	$(10,038,306,201.58)
Turkey	$ 104.00	$ (71,703,554.20)	$ (133,319,088.04)	$ (998,148,138.27)	$ (34,603,155.24)	$ (773,962,646.88)	$ (9,587,063,797.84)
South Africa	$ 109.00	$ 1,868,576.85	$ (59,746,956.99)	$ (895,964,622.93)	$ 217,758,337.22	$ (481,854,037.70)	$ (9,336,373,573.54)
Korea	$ 110.00	$ 16,583,003.06	$ (45,032,530.79)	$ (875,527,919.86)	$ 268,230,635.71	$ (423,432,315.86)	$ (9,286,235,528.68)
Canada	$ 113.00	$ 60,726,281.69	$ (889,252.16)	$ (814,217,810.66)	$ 419,647,531.19	$ (248,167,150.35)	$ (9,135,821,394.09)
United States	$ 129.00	$ 296,157,101.03	$ 234,541,567.19	$ (487,230,561.57)	$ 1,227,204,307.08	$ 686,580,399.05	$ (8,333,612,676.33)
Singapore	$ 182.00	$ 1,076,021,690.11	$ 1,014,406,156.26	$ 595,914,701.04	$ 3,902,236,127.19	$ 3,782,931,656.42	$ (5,676,296,298.73)
Brazil	$ 196.00	$ 1,282,023,657.03	$ 1,220,408,123.19	$ 882,028,543.99	$ 4,608,848,306.09	$ 4,600,835,762.15	$ (4,974,363,670.69)
France	$ 202.00	$ 1,370,310,214.29	$ 1,308,694,680.44	$ 1,004,648,762.40	$ 4,911,682,097.05	$ 4,951,366,093.17	$ (4,673,535,401.52)
Netherlands	$ 211.00	$ 1,502,740,050.17	$ 1,441,124,516.33	$ 1,188,579,090.02	$ 5,365,932,783.48	$ 5,477,161,589.70	$ (4,222,292,997.78)
United Kingdom	$ 229.00	$ 1,767,599,721.93	$ 1,705,984,188.09	$ 1,556,439,745.24	$ 6,274,434,156.35	$ 6,528,752,582.77	$ (3,319,808,190.30)
Japan	$ 239.00	$ 1,914,743,984.02	$ 1,853,128,450.18	$ 1,760,806,775.92	$ 6,779,157,141.28	$ 7,112,969,801.15	$ (2,818,427,741.69)
Australia	$ 248.00	$ 2,047,173,819.90	$ 1,985,558,286.06	$ 1,944,737,103.53	$ 7,233,407,827.71	$ 7,638,765,297.68	$ (2,367,185,337.95)
Italy	$ 280.00	$ 2,518,035,458.59	$ 2,456,419,924.75	$ 2,598,711,601.71	$ 8,848,521,379.48	$ 9,508,260,396.48	$ (762,767,902.42)
Germany	$ 353.00	$ 3,592,188,571.85	$ 3,530,573,038.00	$ 4,090,590,925.68	$12,532,999,169.45	$13,773,046,090.60	$ 2,897,309,372.39
Denmark	$ 357.90	$ 3,664,289,260.27	$ 3,602,673,726.43	$ 4,190,730,770.72	$12,780,313,432.06	$14,059,312,527.60	$ 3,142,985,792.20
World Average	***$ 133.70***	**$ 365,314,904.21**	**$ 303,699,370.37**	**$ (391,178,057.15)**	**$ 1,464,424,109.99**	**$ 961,162,491.68**	**$ (8,097,963,865.49)**
Breakeven Price		$ 108.87	$ 113.06	$ 152.84	$ 104.69	$ 117.25	$ 295.21

Table 3: NPV of NB at a 4% Discount Rate

Every project highlighted in green has a positive net present value of net benefits, meaning that the investment would be profitable. Of profitable projects, the average net benefits are $3.56 billion. At the world average price, 4 out of 6 projects are found to be profitable. In addition to calculating the potential net benefits of each project for each electricity price, we also estimated the breakeven electricity prices for each project at a 4% discount rate. The breakeven prices range from $108.87 – $295.21 per MWh, with a mean of $148.65 per MWh and a median of $115.16 per MWh. The UK project acts as an outlier throughout this study, rarely passing a CBA due to much higher LCOE estimates.

10% Discount Rate Assumption

Our second set of analyses utilizes a 10% discount rate to capture more risk-averse investors, as a higher discount rate would coincide with higher risk, more short-term investing, or with businesses in general as they may be able to receive a higher rate of return investing in other projects. It is important to note that there is a sense of risk associated with nuclear technology impacts on health and safety as mentioned above. Even though this is the case, the financial modularity of SMRs allows revenue to be earned much quicker than traditional nuclear power plants, thereby lowering the comparative rate. The results from this analysis are found in Table 4.

Net Present Value of Net Benefits Under Different Project Assumptions (10% Discount Rate)

Country	Electricity Price: (USD/MWh)	Project 1: PWR-90(1) single module plant	Project 2: PWR-90(2) single module plant	Project 3: PWR-125 five module plant	Project 4: PWR-302 twin-unit land-based	Project 5: PWR-335 two twin-units	Project 6: UK SMR Estimation
Saudi Arabia	$ 48.00	$ (1,054,541,084.00)	$ (1,105,883,424.21)	$ (2,213,382,855.83)	$ (3,441,095,542.91)	$ (4,594,614,886.89)	$ (11,378,271,131.27)
Russia	$ 61.00	$ (978,610,315.28)	$ (1,029,952,655.49)	$ (2,107,923,454.83)	$ (3,180,643,632.03)	$ (4,293,141,612.56)	$ (11,119,544,067.48)
Mexico	$ 63.00	$ (966,928,658.56)	$ (1,018,270,998.76)	$ (2,091,698,931.60)	$ (3,140,574,107.28)	$ (4,246,761,108.81)	$ (11,079,739,903.82)
India	$ 66.00	$ (949,406,173.47)	$ (1,000,748,513.67)	$ (2,067,362,146.75)	$ (3,080,469,820.15)	$ (4,177,190,353.20)	$ (11,020,033,658.33)
Indonesia	$ 77.00	$ (885,157,061.47)	$ (936,499,401.68)	$ (1,978,127,268.98)	$ (2,860,087,434.02)	$ (3,922,097,582.61)	$ (10,801,110,758.20)
China	$ 81.00	$ (861,793,748.02)	$ (913,136,088.23)	$ (1,945,678,222.52)	$ (2,779,948,384.51)	$ (3,829,336,575.12)	$ (10,721,502,430.88)
Argentina	$ 95.00	$ (780,022,150.93)	$ (831,364,491.14)	$ (1,832,106,559.90)	$ (2,499,461,711.25)	$ (3,504,673,048.92)	$ (10,442,873,285.26)
Turkey	$ 104.00	$ (727,454,695.66)	$ (778,797,035.87)	$ (1,759,096,205.36)	$ (2,319,148,849.87)	$ (3,295,960,782.08)	$ (10,263,754,548.78)
South Africa	$ 109.00	$ (698,250,553.85)	$ (749,592,894.06)	$ (1,718,534,897.28)	$ (2,218,975,037.99)	$ (3,180,009,522.72)	$ (10,164,244,139.63)
Korea	$ 110.00	$ (692,409,725.49)	$ (743,752,065.69)	$ (1,710,422,635.67)	$ (2,198,940,275.62)	$ (3,156,819,270.85)	$ (10,144,342,057.80)
Canada	$ 113.00	$ (674,887,240.40)	$ (726,229,580.60)	$ (1,686,085,850.82)	$ (2,138,835,988.49)	$ (3,087,248,515.23)	$ (10,084,635,812.31)
United States	$ 129.00	$ (581,433,986.58)	$ (632,776,326.79)	$ (1,556,289,664.97)	$ (1,818,279,790.48)	$ (2,716,204,485.28)	$ (9,766,202,503.03)
Singapore	$ 182.00	$ (271,870,083.34)	$ (323,212,423.54)	$ (1,126,339,799.35)	$ (756,437,384.57)	$ (1,487,121,136.09)	$ (8,711,392,166.03)
Brazil	$ 196.00	$ (190,098,486.25)	$ (241,440,826.46)	$ (1,012,768,136.73)	$ (475,950,711.31)	$ (1,162,457,609.88)	$ (8,432,763,020.41)
France	$ 202.00	$ (155,053,516.07)	$ (206,395,856.28)	$ (964,094,567.04)	$ (355,742,137.06)	$ (1,023,316,098.65)	$ (8,313,350,529.43)
Netherlands	$ 211.00	$ (102,486,060.80)	$ (153,828,401.01)	$ (891,084,212.50)	$ (175,429,275.67)	$ (814,603,831.81)	$ (8,134,231,792.96)
United Kingdom	$ 229.00	$ 2,648,849.74	$ (48,693,490.47)	$ (745,063,503.42)	$ 185,196,447.09	$ (397,179,298.12)	$ (7,775,994,320.02)
Japan	$ 239.00	$ 61,057,133.37	$ 9,714,793.16	$ (663,940,887.26)	$ 385,544,070.84	$ (165,276,779.40)	$ (7,576,973,501.71)
Australia	$ 248.00	$ 113,624,588.64	$ 62,282,248.43	$ (590,930,532.72)	$ 565,856,932.23	$ 43,435,487.44	$ (7,397,854,765.24)
Italy	$ 280.00	$ 300,531,096.26	$ 249,188,756.05	$ (331,338,161.02)	$ 1,206,969,328.25	$ 785,523,547.33	$ (6,760,988,146.68)
Germany	$ 353.00	$ 726,911,566.77	$ 675,569,226.56	$ 260,856,936.91	$ 2,669,506,981.67	$ 2,478,411,933.97	$ (5,308,136,173.08)
Denmark	$ 357.90	$ 755,531,625.75	$ 704,189,285.54	$ 300,607,018.83	$ 2,767,677,317.31	$ 2,592,044,168.14	$ (5,210,615,972.11)
World Average	***$ 133.70***	**$ (553,982,093.28)**	**$ (605,324,433.49)**	**$ (1,518,162,035.38)**	**$ (1,724,116,407.31)**	**$ (2,607,210,301.49)**	**$ (9,672,662,718.43)**
Breakeven Price		$ 228.55	$ 237.34	$ 320.84	$ 219.76	$ 246.13	$ 619.71

Table 4: NPV of NB at a 10% Discount Rate

There is a negative 65% change in profitable projects as we shift from a 4% to 10% discount rate. This makes intuitive sense, as increasing the discount rate puts more emphasis on the present, where there are expensive upfront costs. Of profitable projects, the average net benefits are $778 million. At the world average price, no projects are found to be profitable. Estimated project-specific breakeven prices at a 4% discount rate range from $228.55 – $619.71 per MWh, with a mean of $312.06 per MWh and a median of $237.34 per MWh. The UK project remains an outlier.

We believe this analysis solidifies the potential for SMR investment in countries with multiple profitable projects, such as Japan, Italy, Australia, Germany, and Denmark.

Country-Specific Discount Rate Assumption

Finally, for each country analyzed we obtained the central bank rates and used them in the calculation for each respective country. We believe that using both a country-specific discount rate and a country-specific electricity price would more accurately reflect the situation in the country itself, including macroeconomic conditions and risk perceptions. The results from this analysis are found in Table 5.

Net Present Value of Net Benefits
Under Different Project Assumptions (Country-Based Discount Rate)

Country	**Central Bank Rate**	**Electricity Price:** (USD/MWh)	**Project 1:** PWR-90(1) single module plant	**Project 2:** PWR-90(2) single module plant	**Project 3:** PWR-125 five module plant	**Project 4:** PWR-302 twin-unit land-based	**Project 5:** PWR-335 two twin-units	**Project 6:** UK SMR Estimation
Saudi Arabia	1.00%	$ 48.00	$ (532,470,513.20)	$ (609,258,179.46)	$ (1,859,362,512.43)	$ (1,563,048,422.15)	$ (2,723,856,098.58)	$ (13,457,629,366.26)
Russia	4.25%	$ 61.00	$ (729,333,176.07)	$ (790,202,109.04)	$ (1,900,634,683.65)	$ (2,292,914,880.30)	$ (3,379,067,248.26)	$ (11,714,669,028.36)
Mexico	4.00%	$ 63.00	$ (674,995,028.77)	$ (736,610,562.61)	$ (1,836,052,964.06)	$ (2,103,967,393.44)	$ (3,169,253,242.21)	$ (11,642,723,637.11)
India	4.00%	$ 66.00	$ (630,851,750.14)	$ (692,467,283.98)	$ (1,774,742,854.86)	$ (1,952,550,497.97)	$ (2,993,988,076.70)	$ (11,492,309,502.53)
Indonesia	3.50%	$ 77.00	$ (385,964,764.25)	$ (449,236,161.43)	$ (1,458,770,048.03)	$ (1,106,878,087.77)	$ (2,034,844,825.26)	$ (10,908,957,716.34)
China	3.85%	$ 81.00	$ (384,839,016.85)	$ (446,927,348.13)	$ (1,439,953,465.69)	$ (1,107,074,697.28)	$ (2,020,980,771.60)	$ (10,725,733,993.00)
Argentina	38.00%	$ 95.00	$ (918,130,458.62)	$ (957,025,762.69)	$ (1,842,404,376.93)	$ (3,015,885,127.63)	$ (3,954,175,494.71)	$ (9,026,125,076.67)
Turkey	17.00%	$ 104.00	$ (888,526,697.52)	$ (934,895,758.28)	$ (1,910,280,327.06)	$ (2,888,704,664.18)	$ (3,895,984,763.00)	$ (10,058,495,959.86)
South Africa	3.50%	$ 109.00	$ 137,294,066.82	$ 74,022,669.64	$ (732,021,671.54)	$ 687,964,302.66	$ 42,686,533.66	$ (9,126,001,699.35)
Korea	0.50%	$ 110.00	$ 1,770,842,947.60	$ 1,689,632,191.93	$ 1,275,180,573.79	$ 6,352,772,850.80	$ 6,386,028,813.64	$ (6,279,973,426.22)
Canada	0.25%	$ 113.00	$ 2,124,749,471.87	$ 2,040,991,358.64	$ 1,729,568,448.56	$ 7,575,453,672.15	$ 7,770,940,885.49	$ (5,460,324,598.07)
United States	0.25%	$ 129.00	$ 2,733,947,406.85	$ 2,650,189,293.63	$ 2,575,676,691.60	$ 9,665,077,798.77	$ 10,189,682,316.24	$ (3,384,539,041.83)
Singapore	0.18%	$ 182.00	$ 4,883,373,309.88	$ 4,798,856,511.86	$ 5,549,926,292.67	$ 17,040,476,389.84	$ 18,717,674,715.73	$ 3,824,391,608.74
Brazil	2.00%	$ 196.00	$ 2,743,815,446.46	$ 2,673,796,539.35	$ 2,789,745,724.81	$ 9,651,799,219.68	$ 10,337,961,562.12	$ (1,267,643,874.53)
France	0.00%	$ 202.00	$ 6,062,480,640.00	$ 5,975,914,320.00	$ 7,157,686,500.00	$ 21,091,990,214.40	$ 23,382,892,800.00	$ 7,531,322,400.00
Netherlands	0.00%	$ 211.00	$ 6,432,870,960.00	$ 6,346,304,640.00	$ 7,672,117,500.00	$ 22,362,474,739.20	$ 24,853,479,552.00	$ 8,793,393,120.00
United Kingdom	0.10%	$ 229.00	$ 6,912,903,667.72	$ 6,827,493,916.13	$ 8,355,696,216.79	$ 24,005,079,017.50	$ 26,768,571,201.47	$ 10,604,430,164.72
Japan	-0.10%	$ 239.00	$ 7,870,253,637.03	$ 7,782,483,870.57	$ 9,650,932,068.31	$ 27,297,002,746.01	$ 30,550,864,887.42	$ 13,508,663,359.72
Australia	0.10%	$ 248.00	$ 7,670,709,724.35	$ 7,585,299,972.76	$ 9,408,204,628.78	$ 26,604,447,348.06	$ 29,777,341,915.21	$ 13,186,584,135.46
Italy	0.00%	$ 280.00	$ 9,272,530,080.00	$ 9,185,963,760.00	$ 11,616,088,500.00	$ 32,102,856,096.00	$ 36,127,977,984.00	$ 18,469,268,640.00
Germany	0.00%	$ 353.00	$ 12,276,807,120.00	$ 12,190,240,800.00	$ 15,788,695,500.00	$ 42,407,897,241.60	$ 48,056,070,528.00	$ 28,706,064,480.00
Denmark	-0.60%	$ 357.90	$ 15,435,165,023.23	$ 15,340,591,186.78	$ 20,058,527,417.43	$ 53,268,921,540.38	$ 60,532,335,553.92	$ 38,253,699,841.85
World Average	***3.72%***	***$ 133.70***	**$ 460,210,752.20**	**$ 397,696,530.51**	**$ (272,484,132.63)**	**$ 1,793,011,194.35**	**$ 1,330,797,907.63**	**$ (7,910,882,754.62)**

Table 5: NPV of NB at Country-Specific Discount Rates

There is a positive 24% change in profitable projects as we shift from a 4% to a country-specific discount rate. Of profitable projects, the average net benefits are $13.5 billion, much higher than under other discount rate assumptions. This is because many projects are analyzed at rates less than 0.50%. At the world average price, 4 projects are found to be profitable.

At the country level, no new countries moved into the profitable zone by changing the discount rate. However, 16 projects that were previously unprofitable in a country with became profitable. Other than this, using a floating discount rate strengthened the profitability of already profitable projects. It is also interesting to note that as electricity prices rise, there seems to be a general trend for discount rates to fall – reaching negative values for Japan and Denmark, countries with two of the highest electricity prices.

Country-Level Breakeven Prices and Rates

After conducting analyses, we also found breakeven prices and breakeven discount rates for each project in each country. These are the prices or rates that, if achieved, would push the investments into profitable ones. The results of breakeven discount prices and rates are shown in Table 6 and 7, respectively.

Breakeven Discount Rates by Country Under Different Project Assumptions

Country	Central Bank Rate	Electricity Price: (USD/MWh)	Project 1: PWR-90(1) single module plant	Project 2: PWR-90(2) single module plant	Project 3: PWR-125 five module plant	Project 4: PWR-302 twin-unit land-based	Project 5: PWR-335 two twin-units	Project 6: UK SMR Estimation
Saudi Arabia	1.00%	$ 48.00	-0.74%	-0.96%	-2.91%	-0.51%	-1.17%	n/a
Russia	4.25%	$ 61.00	0.61%	0.40%	-1.33%	0.83%	0.20%	n/a
Mexico	4.00%	$ 63.00	0.79%	0.58%	-1.13%	1.01%	0.38%	n/a
India	4.00%	$ 66.00	1.05%	0.84%	-0.86%	1.26%	0.63%	-7.15%
Indonesia	3.50%	$ 77.00	1.91%	1.70%	0.02%	2.14%	1.49%	-4.57%
China	3.85%	$ 81.00	2.20%	1.99%	0.30%	2.43%	1.78%	-4.05%
Argentina	38.00%	$ 95.00	3.15%	2.92%	1.19%	3.39%	2.70%	-2.73%
Turkey	17.00%	$ 104.00	3.71%	3.47%	1.69%	3.96%	3.25%	-2.11%
South Africa	3.50%	$ 109.00	4.01%	3.77%	1.96%	4.26%	3.54%	-1.81%
Korea	0.50%	$ 110.00	4.07%	3.82%	2.01%	4.32%	3.59%	-1.75%
Canada	0.25%	$ 113.00	4.24%	4.00%	2.17%	4.50%	3.76%	-1.58%
United States	0.25%	$ 129.00	5.14%	4.88%	2.95%	5.42%	4.63%	-0.79%
Singapore	0.18%	$ 182.00	7.84%	7.51%	5.18%	8.18%	7.20%	1.14%
Brazil	2.00%	$ 196.00	8.50%	8.16%	5.71%	8.87%	7.84%	1.56%
France	0.00%	$ 202.00	8.78%	8.43%	5.93%	9.16%	8.10%	1.73%
Netherlands	0.00%	$ 211.00	9.20%	8.84%	6.26%	9.59%	8.50%	1.97%
United Kingdom	0.10%	$ 229.00	10.02%	9.64%	6.91%	10.43%	9.28%	2.45%
Japan	-0.10%	$ 239.00	10.47%	10.07%	7.26%	10.89%	9.70%	2.70%
Australia	0.10%	$ 248.00	10.87%	10.46%	7.58%	11.31%	10.08%	2.92%
Italy	0.00%	$ 280.00	12.26%	11.82%	8.66%	12.74%	11.40%	3.66%
Germany	0.00%	$ 353.00	15.31%	14.77%	11.02%	15.88%	14.27%	5.21%
Denmark	-0.60%	$ 357.90	15.47%	14.93%	11.15%	16.04%	14.43%	5.28%
World Average	***3.72%***	***$ 133.70***	**5.39%**	**5.13%**	**3.16%**	**5.68%**	**4.87%**	**-0.59%**

Table 6: Breakeven Discount Rate by Country

The results above show the discount rate that would make each project profitable with current electricity prices. Red highlights indicate that the current discount rate is higher than the one in each cell. In the case of Project 6 in Saudi Arabia, Russia, and Mexico, no discount rate would be possible to make the investment profitable. Excluding those results, the average discount rate necessary for a profitable investment in SMR technology is 4.86%.

These results are extremely important for both policy-related decisions and investment decisions. Central banks can directly control their discount rates, meaning they could raise or lower them with regards to these results, if needed. For individual investors, they may be able to use this information to invest if discount rates change in the near future.

Breakeven Prices by Country Under Different Project Assumptions

Country	Central Bank Rate	Electricity Price: (USD/MWh)	Project 1: PWR-90(1) single module plant	Project 2: PWR-90(2) single module plant	Project 3: PWR-125 five module plant	Project 4: PWR-302 twin-unit land-based	Project 5: PWR-335 two twin-units	Project 6: UK SMR Estimation
Saudi Arabia	1.00%	$ 48.00	$ 65.46	$ 67.98	$ 91.89	$ 62.94	$ 70.49	$ 177.49
Russia	4.25%	$ 61.00	$ 113.14	$ 117.49	$ 158.83	$ 108.79	$ 121.84	$ 306.78
Mexico	4.00%	$ 63.00	$ 108.87	$ 113.06	$ 152.84	$ 104.69	$ 117.25	$ 295.21
India	4.00%	$ 66.00	$ 108.87	$ 113.06	$ 152.84	$ 104.69	$ 117.25	$ 295.21
Indonesia	3.50%	$ 77.00	$ 100.60	$ 104.47	$ 141.23	$ 96.73	$ 108.34	$ 272.79
China	3.85%	$ 81.00	$ 106.35	$ 110.44	$ 149.30	$ 102.26	$ 114.54	$ 288.38
Argentina	38.00%	$ 95.00	$ 1,031.39	$ 1,071.06	$ 1,447.91	$ 991.72	$ 1,110.73	$ 2,796.66
Turkey	17.00%	$ 104.00	$ 395.44	$ 410.65	$ 555.14	$ 380.23	$ 425.86	$ 1,072.25
South Africa	3.50%	$ 109.00	$ 100.60	$ 104.47	$ 141.23	$ 96.73	$ 108.34	$ 272.79
Korea	0.50%	$ 110.00	$ 59.83	$ 62.13	$ 83.99	$ 57.52	$ 64.43	$ 162.22
Canada	0.25%	$ 113.00	$ 57.20	$ 59.40	$ 80.29	$ 55.00	$ 61.60	$ 155.09
United States	0.25%	$ 129.00	$ 57.20	$ 59.40	$ 80.29	$ 55.00	$ 61.60	$ 155.09
Singapore	0.18%	$ 182.00	$ 56.48	$ 58.65	$ 79.29	$ 54.31	$ 60.83	$ 153.15
Brazil	2.00%	$ 196.00	$ 78.18	$ 81.18	$ 109.75	$ 75.17	$ 84.19	$ 211.98
France	0.00%	$ 202.00	$ 54.69	$ 56.79	$ 76.78	$ 52.59	$ 58.90	$ 148.29
Netherlands	0.00%	$ 211.00	$ 54.69	$ 56.79	$ 76.78	$ 52.59	$ 58.90	$ 148.29
United Kingdom	0.10%	$ 229.00	$ 55.68	$ 57.82	$ 78.16	$ 53.54	$ 59.96	$ 150.97
Japan	-0.10%	$ 239.00	$ 53.72	$ 55.79	$ 75.42	$ 51.66	$ 57.85	$ 145.67
Australia	0.10%	$ 248.00	$ 55.68	$ 57.82	$ 78.16	$ 53.54	$ 59.96	$ 150.97
Italy	0.00%	$ 280.00	$ 54.69	$ 56.79	$ 76.78	$ 52.59	$ 58.90	$ 148.29
Germany	0.00%	$ 353.00	$ 54.69	$ 56.79	$ 76.78	$ 52.59	$ 58.90	$ 148.29
Denmark	-0.60%	$ 357.90	$ 49.18	$ 51.07	$ 69.04	$ 47.29	$ 52.96	$ 133.36
World Average	***3.72%***	***$ 133.70***	**$ 104.20**	**$ 108.20**	**$ 146.28**	**$ 100.19**	**$ 112.21**	**$ 282.54**

Table 7: Breakeven Electricity Prices by Country

The results above show the residential electricity price that would make each project profitable with current country discount rates. Red highlights indicate that the current price is lower than the individually calculated breakeven price. The average electricity price necessary for a profitable investment in SMR technology is $178.28 per MWh. Excluding Argentina and Turkey, which have high estimated prices due to uncommonly high discount rates, the average electricity price is $98.70 per MWh, lower than the current world average price.

Discussion

Over the course of discussing these results, we analyzed the importance on a country level, created a map of potential investments, and discussed public policy options.

Country Results

On a country-by-country basis, these results are somewhat surprising. Several designs are currently being considered, constructed, or being to be put in operation. As of 2011, several SMR designs were being considered in China, India, Russia, Argentina, Japan, South Korea, and the United States (21). Of those countries, about half (China, India, Russia, and Argentina) do not seem to have a viable option for SMR implementation under the market conditions we analyzed. On the other hand, Japan, South Korea, and the United States do. While SMRs are being designed in all 7 of these countries, they could be installed within the country of origin or shipped to an end location out of the country with a more profitable return. For example, the recently approved American NuScale design may be able to ship modules to either Canada or the United States at relatively low costs due to the primary factory location in Idaho.

The United States seems ready for investment in SMR technology having an average net benefits of $54.6 million across all discount rate assumptions. Since a 10% discount rate is likely too high due to the modularity of SMRs, excluding these analyses increases the average net benefits to $1.5 billion. As closures of coal plants continue and traditional nuclear reactors continue to be decommissioned due to age, new investment in low-GHG baseload generation will be necessary. SMR technology seems to be a possible option for the United States.

Germany also seems to be one of the safer countries to invest in SMRs due to its high electricity price of $353. In 2019, Germany's generation mix comprised of 46% renewables, 29% coal, 14% nuclear, and 10% natural gas (28). The reliance on intermittent renewables can be one of the causes of the rise in electricity prices, which may continue to increase as Germany has voted to shut down all nuclear power plants by 2022 in the wake of the Fukushima disaster in favor of building coal plants in the short run (29). With high electricity prices, there would be room for Germany to use SMRs as a short run solution to baseload generation as opposed to coal, but this may not be feasible due to political pressure.

Regardless of assumptions used, Saudi Arabia, Russia, Mexico, India, Indonesia, China, Argentina, and Turkey have not shown positive net benefits in our analyses. Following is a discussion of why each country may or may not be suited for SMR technology under current conditions:

- *Saudi Arabia* – 99.9% of energy generation currently comes from natural gas and oil. There are plans to increase electricity generation due to increased demand, but there is skepticism about planned nuclear and renewable projects (30).
- *Russia* – More than 1/6 of Russian electricity generation is currently from nuclear, but 60% of the current nuclear fleet is classified as aging with some using the same reactor design as Chernobyl. As of now, there is a federal target to achieve 50% nuclear power share of total generation by 2050, ramping up to 80% in 2100. SMRs may be able to serve as a viable option to do so only if they can beat out traditional nuclear (31).
- *Mexico* – Mexico has a surplus of electricity, being a modest exporter of electricity to the United States (32). While there are plans for more investment in traditional nuclear, this surplus has kept electricity prices too low for SMR investment to be viable.
- *India* – As of 2019, 100% of Indian villages was connected to some form of electricity, up from 2018 levels in which 5% of the population lacked basic access to electricity (33).

Prices are expected to rise as more renewables and traditional nuclear is implemented to meet emission standards. As of now, SMRs may only be viable in remote locations.

- *Indonesia* – Exporting nearly 80% of its coal production, making the country the world's leading exporter of coal. Indonesia also generates 47% of its own electricity from coal and has a lack renewable and nuclear investments, keeping electricity prices low (34). Under current conditions, Indonesia may not be a viable location for SMR investment unless used in remote locations traditional generation may not be able to reach.
- *China* – China has been in a period of economic growth supplemented by simultaneous investments in renewables and coal. Currently, 69% of China's electricity comes from coal, but China is also the world's largest producer of wind energy and has made sizable investments in solar (35). There are plans for traditional nuclear investment, so SMRs may become viable in our model in the near future.
- *Argentina & Turkey* – The central bank rates for both Argentina and Turkey are high, at 38% and 17%, respectively (27). Due to these high rates, it is difficult to make the case for any nuclear project, unless the nation can rely on foreign direct investment.

Map of Potential Investments

The two main variable inputs in our analysis, regardless of country, are the discount rate and electricity price (USD/MWh). These values could vary within a country as different electricity companies could charge different electricity prices or utilize different discount rates. As such, we created a map of potential SMR investment net benefits under different discount rate and electricity price assumptions, as seen in Figure 1.

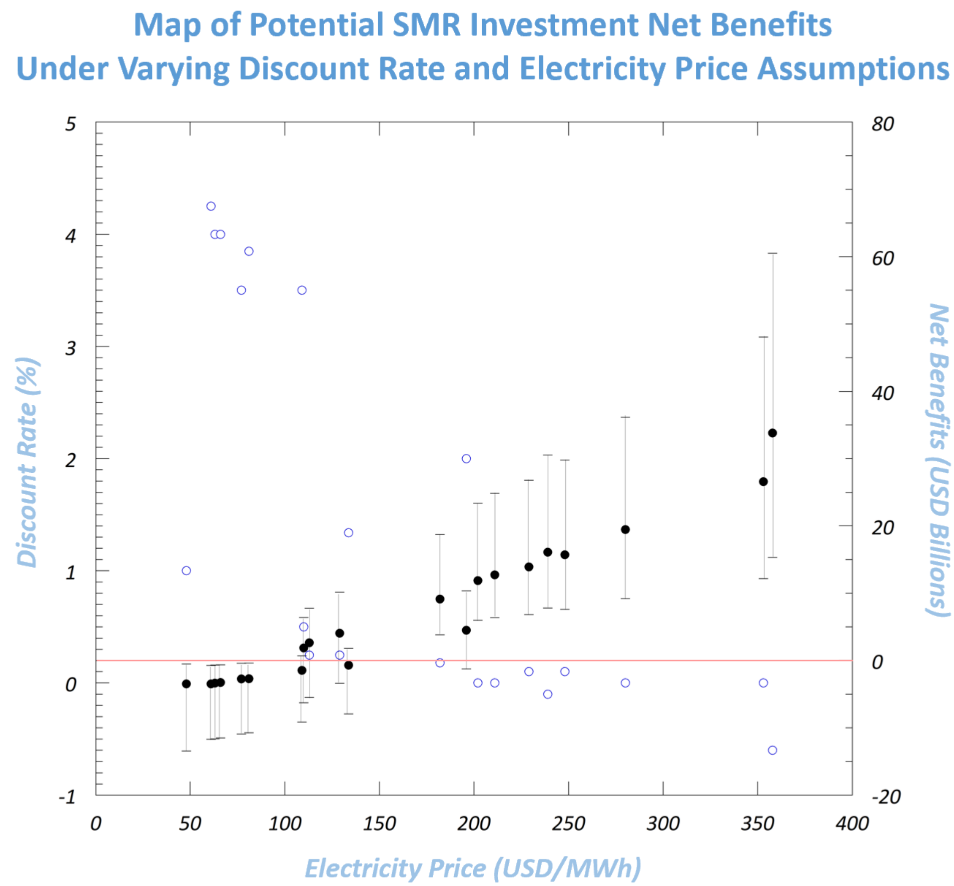

Figure 1: Map of Potential SMR Investment Net Benefits

In Figure 1, each combination of discount rate and electricity price is represented by a blue outlined dot and corresponds with a range of net benefits, where the top of the range is the maximum, the black dot is the average, and the bottom is the minimum. Ranges underneath the red line have projects with a net loss.

Overall, for every project with an electricity price over $200 per MWh and a discount rate below 0.20%, net benefits are positive. Therefore, it would stand to reason that if electricity prices rise above $200 per MWh and rates fall below 0.20 %, an SMR project would be profitable. While this is true given our data, the lack of observations may skew the results. There is a negative correlation between discount rates and electricity prices in our data, which may or may not truly exist. Accessing more observations would improve this prediction.

Potential Policy Improvements

If there is a desire to improve the financial viability of SMRs, federal governments can utilize policy actions to reduce costs. In the United States, the federal government has provided over $51 billion in incentives over the last decade to promote investments in solar and wind powered electricity generation (36). Through these incentives, the U.S. solar industry grew by more than 10,000% (37), now comprises around 8% of American electricity generation, created thousands of jobs, and is expected increase in the future (36). This was achieved through credit incentives, R&D grants, and tax incentives, with the latter comprising 90% of the $51 billion investment. To reach the same level of electricity generation as renewables, estimations show that only $10 billion would be required from the federal government for SMRs, due to much higher capacity factors of these plants (36). This process has begun, as a $50 million subsidy was provided to NuScale by the U.S. DOE (36).

With this level of investment, the LCOE for SMRs is predicted to drop by 22% (36), thereby lowering costs. In our model, such proposed investment would increase the average net benefits for the United States from $54.6 million to $764 million across all discount rate assumptions. Additionally, while excluding the 10% rate, the average net benefits will increase from to $1.5 billion to $2.3 billion. To accelerate commercial deployment of SMRs, federal financial incentives, such as tax credits and credit support, could enhance the economic competitiveness of SMRs through lowered costs and potentially allow this generation source to meet emerging generation market needs (36).

Future Developments

Our analyses can be improved in multiple ways. Firstly, we could improve our benefits calculation by including potential health savings using the value of statistical life and life savings from transitioning from natural gas generation to nuclear. Secondly, we could find more proposed project TEAs to expand our analyses. We could also include electricity price information for multiple years and more countries. Additionally, we could conduct a similar analysis for other forms of generation to compare SMR investment to other options, such as NGCC or battery options. We could factor in state-wide information within the United States to find regions in which SMR investment might make more financial sense. Finally, this type of analysis could be conducted for grid-level battery options that would allow solar and wind to transition to baseload generation and disrupt the current generation process.

After these analyses it would be pertinent to do an examination of foreign direct investment to see whether investment across borders would allow the development of SMRs in nations that have unfavorable discount rates. Additionally, conducting an uncertainty analysis to assign probability distributions to our major results would help solidify this project as being useful for both policy and investment decisions.

Conclusion

Meeting the goal of keeping global mean temperature rise below 2°C through reductions in GHGs will require improvements in energy generation. While renewable generation has grown significantly over the past decade, baseload generation is still primarily dominated by fossil fuels and its hold has been strengthened in the United States and other nations due to historically low natural gas prices (3). SMRs have the potential to be a solid investment to diversify baseload generation due to releasing no GHG emissions, financial modularity, standardized off-site construction, improved energy security, improved safety, and reduced chance of adverse effects (19). With these positive rationales comes concerns – mainly pertaining financial viability. To answer this, we conducted cost benefit analyses under different project, discount rate, and electricity price (USD/MWh) assumptions, and we found breakeven prices/discount rates that would make these investments profitable. Our results revealed favorable investment conditions for 50% or more of the 138 potential projects studied, and for 14 out of 22 countries, including the United States, meaning that SMRs could be both profitable and beneficial to society. We hope that this study can be used by investors, utility companies, and policymakers, to make informed decisions about investment in SMR technology.

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