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Towards a Balanced Assessment of the Viability of Nuclear Energy in the Philippines

ABSTRACT

Nuclear energy in the Philippines has been thrust into the spotlight by the administration of President Duterte. A committee created by Executive Order 116 was tasked to formulate a national position on a possible nuclear program. For nuclear energy to be a sustainable alternative, it must be accepted by society at large. Conventional wisdom surrounding the Bataan Nuclear Power Plant (BNPP) has branded this project as a white elephant leading to rejection of nuclear energy among a significant number of Filipinos, particularly members of civil society. This study presents evidence that the BNPP was operational at the time the administration of President Corazon Aquino decided to shut it down. Moreover, the risks related to the BNPP's location are largely inconsequential. The BNPP became a white elephant because of an ill-advised political decision. Evaluating the viability of nuclear energy in the Philippines should therefore be balanced and deal solely with underlying technical and scientific issues, which are well known. Meanwhile, the role of nuclear energy in promoting a low-carbon society must be re-evaluated because of the sharp decline in the cost of variable renewable energy (VRE). If nuclear energy will eventually be incorporated in the plans of the Department of Energy (DOE), building a new large reactor would be too expensive. Two options are more feasible: revive the BNPP and/or invest in small module reactors (SMRs). Even if the latter has not yet been mainstreamed in the global energy market, SMRs are already on the radar of the DOE.

Keywords: *nuclear energy, Bataan Nuclear Power Plant, white elephant, variable renewable energy, small module reactors*

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INTRODUCTION

Energy security remains a major concern among many developing countries. The International Energy Agency (IEA) defines energy security as "the uninterrupted availability of energy sources at an affordable price". Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance" (*Alonzo and Guanzon 2018*).

Interpreted broadly, energy security is a key component of sustainable economic development. A major implication is that the environmental impact of energy plans and policies has to be taken into account. Energy security, therefore, is aligned with the goal for the world to achieve net-zero carbon emissions by 2050. Net zero means that, on balance, no more carbon is deposited into the atmosphere than is taken out. In order to help achieve this goal, economies of Southeast Asia (SEA) have collectively set a target share of 23% for renewables of the region's primary energy consumption by 2025, a major increase from only 9.4% in 2014 (*Peimani and Taghizadeh-Hesary 2019*). In the Philippines, the goal expressed in the latest Philippine Energy Plan is to increase installed renewable energy (RE) capacity to at least 20,000 MW by 2040 (*DOE 2020*). As of 2019, RE facilities are providing 7,339 MW capacity.

The Philippines has clearly committed to increase the share of RE in its energy mix. However, the share of RE in electricity generation has remained stagnant over the past three decades. In 1990, the share of RE was 45.4% (*Verzola et al. 2018*), and this fell steadily in the succeeding years, reaching 26% in 2010 and 21% in 2019 (**Table 1**). Relying on RE for low-carbon energy in the Philippines either faces major policy constraints (*La Viña et al. 2018*) or does not seem to be a viable strategy in the long run (*Yap and Lagac 2020*). This study looks into the feasibility of nuclear power as an alternative source of low-carbon energy in the Philippines. Given the controversy in the past, the issue of nuclear energy must be approached with a clean slate for there to be a satisfactory resolution to this matter.

Executive Order (EO) 116, directing a study on the possible design of a national nuclear program, was signed by President Rodrigo R. Duterte on July 24, 2020. The Nuclear Energy Program Inter-Agency Committee (NEP-IAC) was subsequently formed with the Secretary of the Department of Energy (DOE) as chairperson. These actions complement the earlier establishment of the Philippine Nuclear Energy Program Implementing Organization (NEPIO) on 24 October 2016. The creation of the NEPIO was one of the major recommendations during a conference on the Prospects of Nuclear Power in the Asia Pacific region hosted by the Philippines in August 2016 under the auspices of the International Atomic Energy Agency (IAEA).

From an historical perspective, both the NEPIO and NEP-IAC appear to be yet another contentious issue raised by the current administration. After all, nuclear energy in the Philippines is associated with the controversial Bataan Nuclear Power Plant (BNPP), considered by some as the epitome of a white elephant (*Mendoza et al. 2018*).

Nevertheless, nuclear power continues to contribute significantly to electricity generation in the world, accounting for 10% of global electricity supply in 2020, which is almost a third of all low-carbon energy (*Was and Allen 2020; World Nuclear Association 2021a*). As of October 2021, 441 nuclear power reactors are in operation in 30 countries, with a combined capacity of 392.1 GW (*IAEA 2020; Statista 2021*). Nuclear power contributes a larger share in advanced economies, accounting for 18% of total generation. However, Germany notably passed legislation to decommission all of the country's nuclear reactors by 2022. This decision was strongly influenced by the 2011 accident in Fukushima, Japan, which conjured memories of the danger posed by the radioactive cloud that swept over Germany following the Chernobyl disaster in 1986.

Despite these prominent disasters, including the Three Mile Island accident in 1979, nuclear power generation remains generally safe and reliable (*Rosen and Dincer 2007; Wheatley et al. 2016*). The experience with nuclear power over six decades shows that it is a secure means of generating electricity. The probability of accidents in nuclear power plants is low and declining. The risks of an accident or terrorist attack on a nuclear plant are generally negligible when compared with other universally accepted hazards. Radiological effects on people of any radioactive releases can be avoided.

This study dissects the nuclear issue in the Philippines along two dimensions. First, the historical and political aspects are assessed by reviewing the controversy surrounding the BNPP. The decision to shut down the BNPP even before it produced a single watt of commercially accessible electricity may have been fundamentally political in nature and this contributed largely to the negative reputation of nuclear energy in the country. Second, the scientific, technical, and economic merits of nuclear energy are analyzed. This aspect

Table 1. Power generation in the Philippines by source showing a declining share of renewable eergy (in GWh).

Technology	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1. Coal	23,301	25,342	28,265	32,081	33,054	36,686	43,303	46,847	51,932	57,890
2. Oil-Based	7,101	3,398	4,254	4,491	5,708	5,886	5,661	3,787	3,173	3,752
3. Combined Cycle	1,202	124	227	247	515	276	694	405	522	728
4. Diesel	4,532	2,762	3,332	3,805	4,730	5,521	4,722	3,100	2,505	2,8115
5. Gas Turbine	3	-	-	-	-	10	-	-	-	26
6. Oil Thermal	1,364	512	695	438	463	80	245	282	145	184
7. Natural Gas	19,518	20,591	19,642	18,791	18,690	18,878	19,854	20,547	21,334	22,354
8. Renewable Energy (RE)	17,823	19,845	20,762	19,903	19,810	20,963	21,979	23,189	23,326	22,044
a. Geothermal	9,929	9,942	10,250	9,605	10,308	11,044	11,070	10,270	10,435	10,691
b. Hydro	7,803	9,698	10,252	10,019	9,137	8,665	8,111	9,611	9,384	8,025
c. Biomass	27	115	183	212	196	367	726	1,013	1,105	1,040
d. Solar	1	1	1	1	17	139	1,097	1,201	1,249	1,246
e. Wind	62	88	75	66	152	748	975	1,094	1,153	1,042
TOTAL	67,743	69,176	72,922	75,266	77,261	82,413	90,798	94,370	99,765	106,041
Share of Coal (%)	34%	37%	39%	43%	43%	45%	48%	50%	52%	54%
Share of Renewable Energy (%)	26%	29%	28%	26%	26%	25%	24%	25%	23%	21%

Source: Department of Energy 2019 Power Statistics.

becomes even more important in an era where variable renewable energy (VRE) has become mainstream.

MATERIALS AND METHODS

This study used qualitative methods through a hermeneutic analysis to understand the history of the Bataan Nuclear Power Plant (BNPP). Based on recorded accounts and interviews with experts who are genuinely familiar with the issue, the basis for BNPP's cessation is evaluated. This was combined with economic and scientific evidence in providing a useful set of information for the Nuclear Energy Program Inter-Agency Committee (NEP-IAC).

Framework and Objective

Following *Ong et al.* (*2021*), a suitable framework for this study would be an analysis of factors that lead either to the acceptance or rejection of nuclear energy by policymakers and society in general. The authors argue that in a democratic country, acceptance by the people iscrucial for programs and projects to be sustainable.

The framework is supported by the empirical results of *Ong et al.* (*2021*), which show that knowledge towards nuclear power plants would be the key factor in determining people's acceptance either positively towards the perceived benefits or negatively because of the perceived risks (**Figure 1**). However, conventional wisdom about the BNPP has a built-in bias and usually leads to the rejection of nuclear energy, particularly among civil society groups (*Mendoza et al. 2018; Aliperio 2020; Vera Files 2020*). Many Filipinos believe that because of the corruption that surrounded the BNPP, the structure was erected in an unsafe area and was defective. The BNPP was, therefore, not operational and became a white elephant. A more accurate historical account sets the stage for an impartial and fact-based discussion on the scientific, technological, and economic aspects of nuclear energy. Reducing or eliminating the bias from misconceptions about the BNPP is therefore a key objective of this study. This is illustrated in the sequence of arrows in bold red font (**Figure 1**). The debate should be steered away from the myths and biases surrounding the BNPP and towards a balanced analysis and evaluation of the viability of nuclear energy.

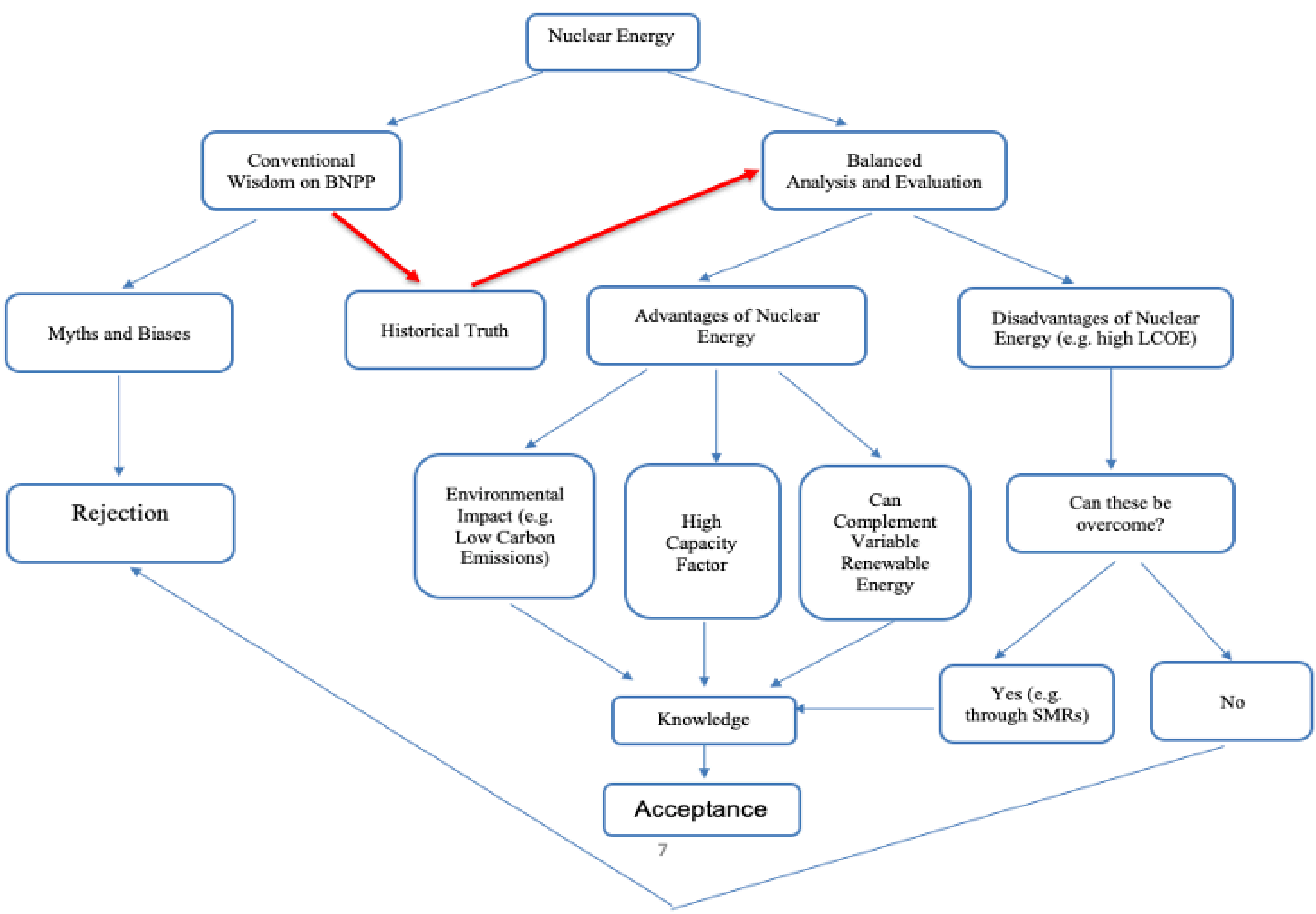

Figure 1. Framework for analyzing factors that lead to acceptance or rejection of nuclear energy.

There are three areas where nuclear energy has a distinct advantage (**Figure 1**): a high-capacity factor;lower greenhouse gas (GHG) emissions; and the ability to complement variable renewable energy. Meanwhile, nuclear energy has its associated risks, and the ability to deal with these will determine whether this option is acceptable to society. The rest of this section elaborates on the historical animosity against nuclear energy. This is juxtaposed against the views of those who were closely involved in the construction of the BNPP and other experts. Once the BNPP debate is resolved, a more science-based discussion of the viability of nuclear energy in the Philippines can be pursued.

Historical Animosity

The administration of then President Corazon Aquino decided not to operate the BNPP on April 30, 1986. The official reasons revolved around fundamental questions concerning its soundness as well as the integrity of the process with which it was planned and implemented. In short, the BNPP officially became a white elephant. *Mendoza et al.* (*2018*) adopt the contemporary definition of white elephants as large-scale, socially unprofitable investment projects that have turned into heavy burdens for businesses and/or governments tasked with their maintenance.

As a framework, the authors look at three alternative explanations of megaproject performance, namely, strategic rent-seeking behavior, misaligned and underdeveloped governance, and diverse project cultures and rationalities. The authoritarian nature of the Marcos government contributed to making all these factors relevant in the case of the BNPP.

A September 1, 1986 article in Fortune magazine titled "The $2.2 Billion Nuclear Fiasco" (*Dumaine 1986*) details the evolution of the BNPP. Rent-seeking was manifest in the process. Initial discussions were between the Marcos government and General Electric and were characterized as professional. However, Westinghouse was able to get an inside track in the project and many sources claimed it was because President Marcos himself received bribes. Eventually, the cost ballooned from an initial price of US$ 650 M for two 620-MW reactors to US$ 2.2 B for a single reactor.

Misaligned and underdeveloped governance usually pertains to internal project arrangements that are not robust enough to adequately manage shocks and uncertainties. In the case of the BNPP, weak governance promoted the rent-seeking behavior. Apart from overpricing, there were also possible construction defects. William Albert, an advisor from the IAEA was brought in by the new government of President Corazon Aquino to do inspections. Albert brought up issues of welding, base plates, pipe hangers, water valves, and transmission cables. He attributed all these shortcomings to quality control (*Dumaine 1986*).

Another issue was the location of the nuclear reactor, which is near a volcano and earthquake fault. More precisely, the "site for the plant is just five miles from a volcano and within 25 miles of three geologic faults" (*Dumaine 1986*). Despite the possible risks, the BNPP was still erected in its present site reflecting the "diverse project cultures and rationalities". A geological study which provided evidence that the proximity of the BNPP to Mount Natib rendered its location geologically unsafe on account of volcanic hazards (*Lagmay et al. 2012* as cited by *Mendoza et al. 2018)*.

The Aquino administration doubled down on its decision to mothball the BNPP by filing a lawsuit against Westinghouse in 1988 in the United States District Court of New Jersey (*Republic of the Philippines and National Power Corp. v. Westinghouse Electric Corp. 1991*). In the same year, Westinghouse filed an arbitration case with the International Chamber of Commerce, which was docketed as Case No. 6401/BGD and fully documented and analyzed by *Martin* (*2004*). In its lawsuit, the Philippine government alleged that Westinghouse bribed President Marcos and the BNPP was overpriced.

In May 1993, the case was finally resolved when Westinghouse was acquitted by a US jury of bribing President Marcos to win the BNPP contract. The other legal case was settled in 1995. As part of the settlement, the Philippines received two units of 501-F Gas Turbines, 100 MW each, and US$ 40.3 M in cash. In exchange, the Philippine government agreed to drop all claims against Westinghouse and assume all remaining financial obligations related to the BNPP. It is quite interesting to note that when the Ramos administration took over the negotiation for a possible settlement in August 1992, the parameters included the possibility of reviving the BNPP. Administrative Order 4 listed the following areas for negotiation (*Administrative Order 4 1992*):

"a) Westinghouse shall make certain payments and provide certain discounts and credits to the Government in amounts at least equal to those stipulated in the Conditional Settlement Agreement of March 4, 1992;

b) Westinghouse will repair and upgrade the BNPP to bring up the plant to current standards of the US Nuclear Regulatory Commission, and at the same time establish the operations organization and provide for training and certification of plant operators;

c) Westinghouse will operate and maintain the BNPP for a period not exceeding thirty years; during which period, Westinghouse shall train Filipinos to take over BNPP operation, management, and engineering."

In an interview with Antonio T. Corpuz (*Pers. Comm. August 6, 2020*), who retired as Senior Vice President for Generation of NPC in 2003, he revealed that there were confidential negotiations between Westinghouse and the Ramos government for a possible upgrade of the BNPP. The cost of the upgrade was based on the Seabrook Nuclear Plant, which was the latest model in the US at that time. The amount would then be compared with the cost of a new coal plant with a Fuel Gas Desulfurizer (FGD). The cost of the upgrade was lower, but when the decision was made, the cost of the FGD- which comprised 30% of the total cost- was not included in the comparison. As a result, the government did not pursue the upgrade. The design of the BNPP made its conversion to a coal plant difficult and as a result it remained mothballed.

Contrarian Views

Unbeknownst to many Filipinos, the BNPP was ready for operation at the time it was mothballed by the Aquino Government. The president of the National Power Corporation (NPC) from May 1986 to November 1987, underscores this fact (*del Rosario 1996*):

"One of my first official actions was to appear in a Cabinet meeting where the nuclear plant was an item on the agenda. It had been one of the main political issues in the presidential snap elections of February 1986, and everyone was clear on where President Aquino stood on the matter. Before she appointed me, somebody close to the new administration asked if I would insist on operating the nuclear plant in case I became NPC president. In view of my involvement in the plant's inception, planning construction, supply negotiations, and financing, I was confident it was built according to the best engineering and nuclear standards in the world, and it should be operated. I came prepared with technical and financing data on the nuclear plant which, I thought, would give Cabinet members a more balanced perspective on the issue. The most important information of all was the fact that the plant was almost ready to operate anytime once the government gave its go signal… "They had apparently made up their minds about not operating the plant. It was useless and untimely for me to bat for its operation. I thought it is regrettable that the nuclear plant was not being judged for its technical merit. It seems to represent all the abuses that Marcos and his cronies stood for, and the decision not to operate it was a fallout of anti-Marcos sentiments. No technical argument could overturn that kind of bias."

This story was corroborated by Mr. Corpuz (*Pers. Comm. August 6, 2020*), who made the following assertions:

- The Philippine government was prepared to operate the BNPP after having undergone a series of systems tests;
- These consisted of Cold Functional tests and Hot Functional tests at which the power plant was synchronized to the Luzon Grid for less than a minute using pump heat;
- Fuel loading was the next step to complete the tests but the licensing proceedings with the Philippine Atomic Energy Commission, which was the regulator at that time, were discontinued when BNPP was mothballed;
- At that time NPC already had licensed nuclear power plant operators and all other disciplines had the requisite local and foreign trainings;
- The Fortune magazine article is not accurate. First, it should be clarified that the US$ 2.2 billion cost included interest charges that accrued even if construction was delayed for 18 months following the Three Mile Island accident in 1979. Meanwhile, design improvements that stemmed from this incident were incorporated in the BNPP and this cost an additional US$ 700 million.
- Second, the alleged defects were "punch list" items which NPC identified and were subject to compliance by Westinghouse. Said punch list items were not a detriment to operating the plant but could have been addressed during the warranty period; and
- The IAEA conducted two Operational Safety and Review inspections and did not report findings that the plant was not safe.

The current administration of the National Power Corporation made a presentation to the NEP-IAC in which it traced the history of the BNPP. The following timeline was presented (*National Power Corporation 2020*):

- June, 1984: Uranium fuel delivered
- July, 1984: IAEA Operational Safety Review Team (OSART) I review: construction appraisal review
- February, 1985: IAEA OSART II review: operational readiness review
- June, 1985: Public hearings began for plant licensing

A country profile prepared by the IAEA dated July 2010 made reference to these events (*IAEA 2010*):

"In May 1984, the plant was fully completed and the hot functional tests of all systems were satisfactorily conducted. The 1985 International Atomic Energy Agency Operational Safety Review Team (IAEA-OSART) performed evaluation of the operational readiness of the plant and it reported that the plant could perform the core loading."

The implication is that the BNPP was technically sound and the decision to have it mothballed could only be justified scientifically by the risks posed by its location. A search of the literature on this topic led to a power point presentation prepared by *Venida and Reyes* (*2011*) who were staff of Department of Science and Technology-Philippine Nuclear Research Institute (DOST-PNRI) at that time. The power point refers to site studies in the following areas: hydrology, meteorology, geology, seismology, and lithology. The results all support the choice of location of the BNPP. However, there is no indication of the time when these studies were conducted. The earliest formal study is attributed to *Solidum* (*2009*).

Meanwhile, Professor Carlo A. Arcilla, Director of the PNRI, recently conducted similar site studies. He is a co-author of the study titled "Is there a fault beneath the Bataan Nuclear Power Plant? A systematic study using electrical resistivity, seismic refraction and radon gas detection" (*Arcilla et al. 2017*). Based on the results of the various geological tests, he and his team concluded that there are no active faults that lie beneath the BNPP. Both Professor Lagmay and Professor Arcilla even acknowledge that the active fault map of the Philippines prepared by PHIVOLCS does not list an active fault in the immediate vicinity of the BNPP.

Its location near active faults was addressed by a structural design intended to withstand a 7.9 magnitude earthquake. Arcilla (*Pers. Comm. July 30, 2020*) emphasized that the earthquake risk of BNPP was rated at 0.4 g, while that of the Fukushima nuclear plant was 0.14 g, i.e. BNPP's structure is 2.8 times stronger. The Fukushima plant withstood the magnitude 9.0–9.1 undersea megathrust earthquake that struck on March 11, 2011.

As to the volcanic hazard posed by Mt. Natib, Arcilla (*Pers. Comm. July 30, 2020*) argues that the only reliable age dates by Carbon 14 testing put the age of the volcano at 27,000 and 60,000 years. This is older than the volcanoes in Laguna de Bay whose age is estimated at 25,000 years. Arcilla (*Pers. Comm. July 30, 2020*) wryly concludes that if the reasoning for closing BNPP is followed, then the cities of Manila and Angeles- because of the latter's proximity to Mt. Pinatubo- should have never been built. Arcilla (*Pers. Comm. July 30, 2020*) suggested that the Philippine Institute of Volcanology and Seismology (PHIVOLCS) should be the final arbiter on this matter.

RESULTS AND DISCUSSION

Economic Cost: An Inconvenient Truth

A possible reason why opponents of the BNPP have been pushing the issue of safety to the forefront is the high economic cost of mothballing the plant. A purely political decision could not justify the widespread consequences. The impact of the decision not to operate the BNPP was exacerbated by slow decision-making on new sources of power to compensate for the shortfall in supply. This resulted in a severe power crisis from 1989–1993. *Alonzo and Guanzon* (*2018*) refer to an Asian Development Bank study that estimated a 6% drop in gross domestic product (GDP) in 1989–1991 that could be attributed to the power crisis.

If the foregone income is calculated based on Asian Development Bank's estimate, then the equivalent amount is US$ 7.94 billion (6% of the combined GDP in 1989–1991) (**Table 2**). It should be noted, however, that the period of long daily power outages lasted until 1993. Based on the pattern of the GDP growth rate, 1990–1993 is the more relevant period in which output losses should be estimated. The economy decelerated quite significantly from the previous two years. A counterfactual growth trajectory is created, which is on the conservative side (**Table 2**). The cumulative change in GDP when comparing the actual growth rates with the higher counterfactual is US$ 12.96 B. This does not even factor in the exorbitant rates consumers had to pay for electricity generated from onerous power agreements that were forged since 1993. The economic cost of not operating the BNPP is at least US$ 13 B.

Scientific Debate: Advantages and Disadvantages of Nuclear Power

Clearly, the decision not to operate the BNPP was dominated by the following considerations:

- It was tainted by corruption, which is supported by the sharp increase in the construction cost;
- It was located near a volcano and earthquake faults (but

Table 2. Comparing historical GDP and GDP growth rates with a counterfactual that assumes Bataan Nuclear Power Plant operation, 1988–1993.

Year	GDP growth rate	GDP in constant prices (PhP, base year 2018)	Counterfactual GDP growth rate	Counterfactual GDP in constant prices (million pesos, base year 2018)	Actual GDP in US$ (million)	Counterfactual GDP in US$
1988	6.8	4,813,453.58				
1989	6.2	5,112,143.35	6.2	5,112,143.35	42,575.18	42,575.18
1990	3.0	5,267,397.42	5.0	5,367,750.52	44,311.59	45,155.81
1991	-0.6	5,236,934.24	3.0	5,528,783.04	45,417.56	47,948.63
1992	0.3	5,254,614.29	3.0	5,694,646.53	52,976.34	57,412.69
1993	2.1	5,365,818.07	4.0	5,922,432.39	54,368.08	60,007.87

Source of basic data: *World Bank* (*2020*).

not on one);

- The Chernobyl disaster on April 26, 1986 shook confidence in nuclear energy; and
- It was a campaign promise of President Aquino during the February 1986 snap election.

As lamented by *del Rosario* (*1996*), "it is regrettable that the nuclear plant was not being judged for its technical merit." A crucial decision was not a product of rigorous scientific and technical analysis and debate.

The expensive lesson from the 1986 experience is that the current effort under EO 116 should be supported by science. The advantages and disadvantages of nuclear energy are well known in the literature (*Brook, et al. 2014; Prăvălie and Bandoc 2018*). These are readily summarized, first with the advantages:

Low Cost of Operation. Constructing a nuclear power plant is very costly resulting in nuclear energy having the highest levelized cost of electricity (LCOE) (**Figure 2**). However, after this large initial outlay, nuclear energy becomes relatively cost-effective in terms of operation and maintenance. Producing electricity from nuclear energy is considerably less costly compared with producing it from gas, coal, or oil. Nuclear energy also has the benefit of greater stability in terms of fluctuation in cost- unlike traditional fossil fuels that experience greater price volatility.

Dependable Source of Energy. Certain energy sources, like solar and wind power, are dependent upon weather conditions, However, nuclear energy does not have to deal with this constraint. Nuclear power plants are, therefore, essentially impervious to external climatic factors resulting in reliable energy output. The result is a higher capacity factor (**Table 3**). The figures imply that nuclear power plants are generating peak power more than 93% of the time during the year, which is higher than all other sources.

Table 3. Capacity Factors of energy generation technologies indicating unreliability of Renwable Energy.

Source	Capacity Factor (%)
Nuclear	93.5
Natural gas	56.8
Coal	47.5
Hydropower	39.1
Wind	34.8
Solar	24.5

Source: *US Department of Energy* (*2021*).

Stable Base Load Energy. This is related to the feature of dispatchability: output can be transmitted to the system as and when required. For example, under ideal conditions wind turbines generate significant amounts of power. Therefore, when the wind is blowing, nuclear plants can adjust their output downward. Conversely, when the wind is not blowing or sun is not shining, nuclear energy can be adjusted to compensate for the drop in generated power from VRE.

Low Pollution Output. Abstracting from the issue of nuclear waste (see below), nuclear energy produces much less pollution compared with fossil fuels. Throughout its life cycle, nuclear produces about the same amount of carbon dioxide-equivalent emissions per unit of electricity as wind, and one-third of the emissions per unit of electricity when compared with solar (**Figure 3**). At current levels of consumption of nuclear energy, the emission of greenhouse gases is reduced by over 555 M MT annually.

Adequate Fuel Availability. Both fossil fuels and the uranium used to operate nuclear power plants have finite supply. However, fossil fuels have much lower lifespan than uranium, whose reserves are estimated to last another 80 years. Switching to nuclear energy might provide the Philippines the added time it needs to develop more reliable and cleaner renewable energy resources.

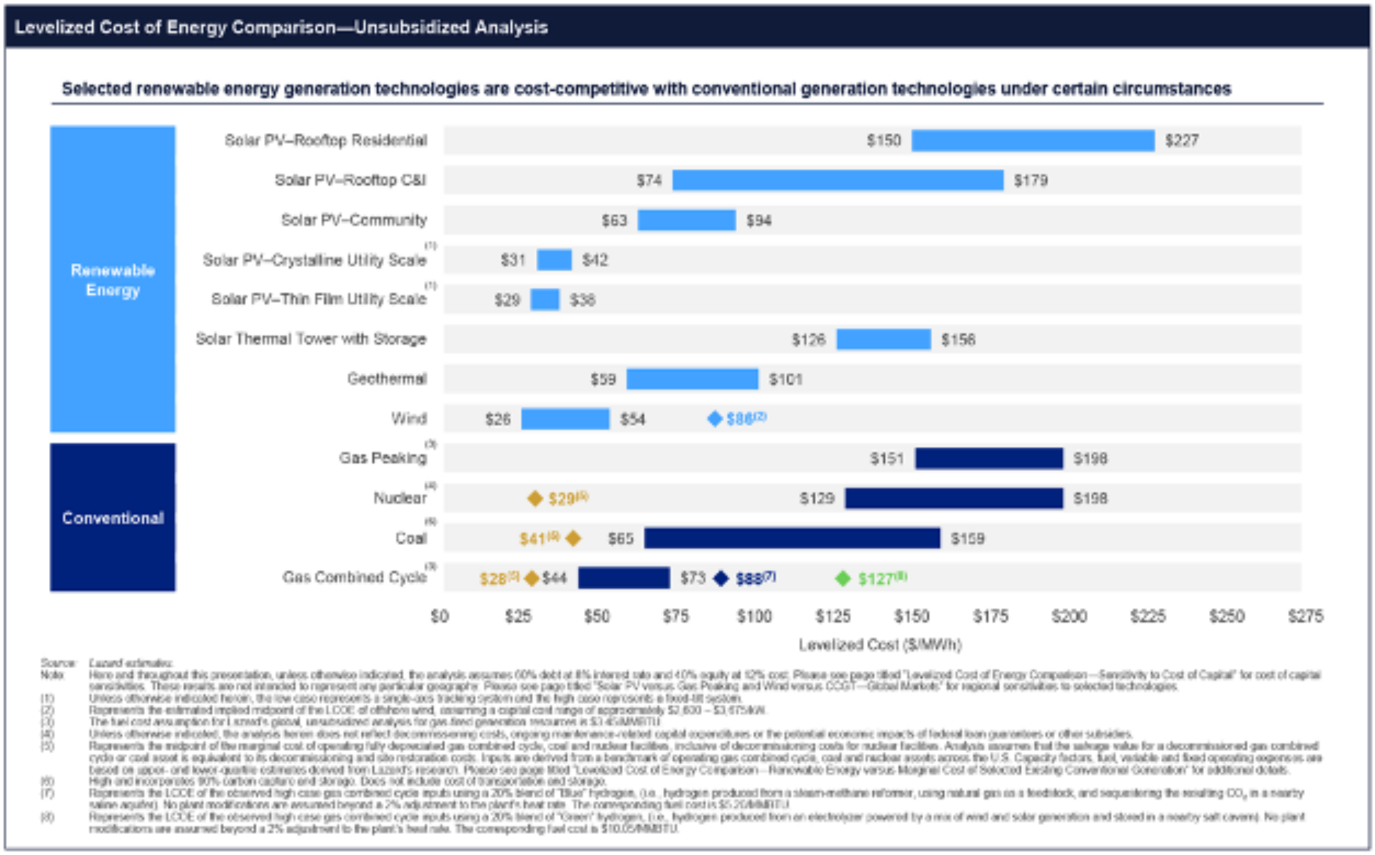

Figure 2. Comparing levelized cost of energy (LCOE) of various energy generation technologies indicating relative costliness of nuclear power (as of October 2020). Source: *Lazard* (*2020*).

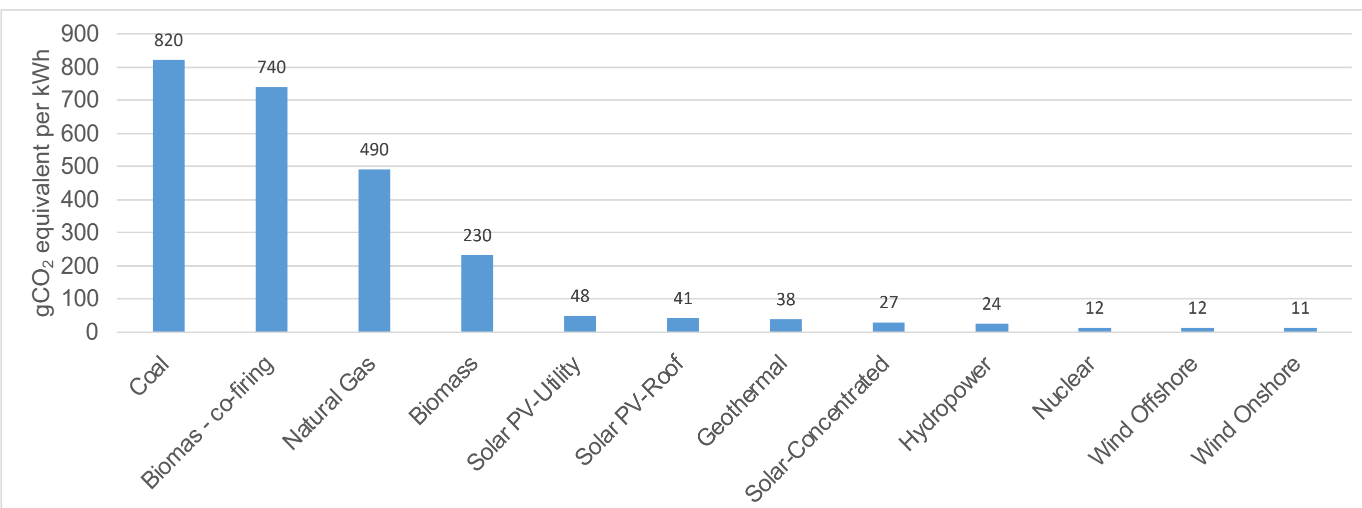

Figure 3. Comparison of GHG emissions of various energy sources based on average life-cycle CO_2 equivalent emissions. Source: *World Nuclear Association* (*2021b*).

Meanwhile, some countries like Russia, India, and China are already making progress toward using the more abundant and environment-friendly thorium as fuel for nuclear reactors. Another area of interest is turning nuclear fusion into a reality. In order to classify nuclear energy as sustainable, the use of breeder reactors and nuclear fusion is required.

High Energy Density. Compared with fossil fuels, nuclear fission is approximately 8,000 times more efficient at generating energy. This results in a substantial amount of energy density. Greater efficiency leads to less waste and makes existing fuel resources available for a larger segment of the population.

As for the disadvantages, these are:

Expensive to Build. As indicated in the previous list, nuclear power plants are cost-effective to operate but very expensive to construct. In addition, the cost has risen sharply. From 2002 to 2008, the cost to build a nuclear plant grew from an estimated US$ 2–US$ 4 B to US$9 billion, and these cost estimates are usually surpassed during construction. A more recent example is the 1.63 GW European Pressurized Reactor being built by Électricité de France in Flamanville. The cost of this Generation III project has ballooned to over US$ 12 billion (*IEA 2019*). In addition to the cost of construction, nuclear energy projects must also budget funds to safeguard the waste that is produced. This normally entails keeping the waste in cooled structures and implementing appropriate security procedures. All of these factors make the cost of nuclear power prohibitive.

Accidents. The three major disasters mentioned earlier- Three Mile Island, Chernobyl, and Fukushima- have created doubt and suspicion among many people about the safety of nuclear power. In particular, the Fukushima crisis in 2011 demonstrated that despite extensive safety measures built into nuclear power plants, accidents can and do happen.

Produces Radioactive Waste. While the use of nuclear energy does not generate any GHG emissions, it does produce radioactive waste that has to be securely stockpiled in order not to pollute the environment. Exposure to small quantities of radiation-such as radioactivity from cosmic rays or radon in the air- is not harmful. However, exposure to radioactive waste from nuclear energy production is quite hazardous.

Nuclear power plants have been contending with the challenge to store radioactive waste. Because it cannot be destroyed, the solution at present is to seal the nuclear waste securely in containers and stockpile these deep underground. This minimizes the chances of the nuclear waste to contaminate the environment. As technology progresses, more suitable ways of stockpiling radioactive waste will be available.

Environmental Impact. Apart from the issue of radioactive waste, nuclear power plants have other adverse impacts on the environment. The mining and enrichment of uranium also has harmful effects. While open-pit mining for uranium has enough safety features to protect miners, the process leaves behind radioactive particles, causes erosion, and even pollutes nearby water sources. Underground mining is not much different as it exposes miners to high levels of radiation during the process of extraction and processing. Radioactive waste rock is also produced.

Security Threat. By its nature, nuclear power poses a distinctive threat to national security. Nuclear power plants are an obvious target for terrorists because of the potential disaster that it could cause. Meanwhile, the uranium used to operate the power plant can be enriched to produce nuclear weapons and the situation can be disastrous if the weapons end up with lawless elements. For these reasons, security related to nuclear materials and nuclear power plants has to be prioritized.

Limited Fuel Supply. If nuclear fusion does not become a reality and/or better breeder reactors are not built, nuclear energy will not be sustainable. The supplies of uranium and thorium will eventually be depleted. In this scenario, nuclear power will only be a temporary source of clean energy, and a very expensive one. Extensive and detailed cost-benefit analysis has to be applied before embarking on a nuclear program.

Nuclear Energy and VRE

How nuclear energy will fit in with the existing realities and the plans and policies of the DOE has to be assessed. The Renewable Energy Act of 2008, together with the Biofuels Act of 2006, was enacted to promote low-carbon energy and at the same time address the Philippines' continuous dependence on imported fossil fuels by promoting the exploration, development, and use of the country's renewable energy sources such as solar, wind, biomass, hydro, and geothermal. The National Renewable Energy Program (NREP) outlines the policy framework and sets out the indicative interim targets within the 2011–2030 timeframe to achieve the goals set forth in the RE Act of 2008.

The DOE is mandated to implement the RE law and to perform the necessary actions for the execution of the policy mechanism set forth by NREP. Several policy mechanisms have been promoted to encourage the development of renewable energy in both on-grid and off-grid systems. Among them is the Renewable Portfolio Standard (RPS) which is a market-based policy that requires power distribution utilities, electric cooperatives, and retail electricity suppliers (RES) to source an agreed portion of their energy supply from eligible RE facilities. The aim is to increase RE utilization by 35%. As mentioned in the background section, this does not seem to be a feasible target (*Yap and Lagac 2020*).

Given the parameters of energy generation in the future, the possible role of nuclear power has to be explored. Both VRE and nuclear power are considered as important low-carbon sources of energy. The literature reveals tensions between advocates of each source in achieving the demands of a low-carbon society. There are several areas where the rivalry manifests.

Foremost is that it takes longer and much costlier to build a nuclear power plant. A summary measure for comparison is the LCOE, which is the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity-generating plant divided by a discounted sum of the actual energy amounts delivered. Nuclear is clearly more expensive than solar and wind (**Figure 2**).

However, the LCOE comparison does not take into account dispatchability. In order to rationalize the nuclear option, the argument is made that it is the only low-carbon energy source that can supply reliable baseload electricity. VRE is not dispatchable. At high levels, sourcing electricity from solar and wind in a grid becomes problematic. In general, there is a discrepancy between supply and demand. Reserve generating capacity is required due to the low capacity factor of solar and wind. System costs increase sharply with a larger share of VRE. The flip side to this argument is the high-capacity factor of nuclear energy (**Table 3**).

Some experts dispute this advantage of nuclear energy (*Diesendorf 2016a*). A related article is titled "Dispelling the nuclear 'baseload' myth: nothing renewables can't do better!" (*Diesendorf 2016b*), The author argues that practical considerations and simulation studies show that the role of baseload power is overrated. Instead, the electricity system can adopt flexibility in its operation so that supply and demand can be matched continuously. The author also maintains that baseload supply can be substituted for energy imports from neighboring regions or countries. This debate can be taken into consideration by the NEP-IAC.

The last area for comparison is the impact of nuclear energy and VRE on the environment. One of the more interesting sources for discussion is a TEDx presentation by Michael Shellenberger (*Shellenberger 2019; Shellenberger 2017*) Some of Shellenberger's key arguments were: "Solar farms require hundreds of times more land, an order of magnitude more mining for materials, and create hundreds of times more waste than do nuclear plants; and wind farms kill hundreds of thousands of threatened and endangered birds, may make the hoary bat go extinct, and kill more people than nuclear plants." Similar analysis has been provided for the entire RE sector (*Vezmar et al. 2014*) detailing the factors that caused experts like Mr. Shellenberger to shift support from VRE to nuclear energy. Meanwhile, issues that were raised in the case of SEA (*Pratiwi and Juerges 2020*) focused on RE's competition for land and water which has an adverse impact on biodiversity conservation.

The LCOE comparison between VRE and nuclear energy does not take into account the social cost of GHG emissions. Nuclear energy has much lower GHG emissions compared with other sources (**Figure 3**). All environmental costs and benefits related to each energy source have to be consolidated with the financial aspects (**Figure 2**) before a sound decision can be made.

There is of course a middle ground. The title of an article captures this position: "Nuclear & Renewables, the Ultimate Power Couple? We Think So" (*Kempfer 2019*). One problem of relying exclusively on VRE is that excess supply is created. If resources like nuclear are incorporated in the system, power can be augmented on command and a significant portion of excess supply can be eliminated. Estimates show that when there is collaboration between nuclear and renewables, the cost of attaining a carbon-free grid could be reduced by as much as 62%. Relatedly, nuclear power plants can be designed to act as energy buffers (*Petrescu et al. 2017*) which highlights their capability for flexible operation, including changing power output over time- ramping orload following- and providing frequency regulation and operating reserves (*Jenkins et al. 2018*). Other studies have shown that combining nuclear energy and VRE is technically feasible (*Ruth et al. 2014; Denholm et al. 2012*).

CONCLUSION AND RECOMMENDATIONS

The goal of the NEP-IAC is to formulate a National Position on a Nuclear Energy Program. The groundwork had already begun through the conduct of energy planning studies on the 19 infrastructure issues of nuclear power development consistent with the IAEA's Milestone Approach. This is reported in the draft of Chapter IX of the Philippine Energy Plan 2018-2040 which is titled "Nuclear Power Program" (*DOE 2020*).

This study provides a framework for the NEP-IAC to craft a national nuclear program that is fair-minded and transparent. There are factors that have to be considered before nuclear energy is accepted or rejected (**Figure 1**).

Biases have to be avoided, particularly those that emerged from the BNPP controversy. The interviews with experts along with the anecdotes of Conrado del Rosario and reports from IAEA have systematically demonstrated that, contrary to conventional wisdom, the BNPP was fully operational when the decision was made to shut it down. Moreover, the issues related to the BNPP's proximity to an earthquake fault and volcano are inconsequential. The BNPP became a white elephant not because it was defective but because of an ill-advised political decision.

Anti-nuclear advocates in the Philippines should therefore refrain from citing the BNPP as proof that nuclear energy is not a feasible option in the Philippines. Instead, the debate must deal solely with the branch corresponding to "Balanced Analysis and Evaluation" Indeed, there are many factors to consider before nuclear energy can be incorporated into the national program of the DOE. The main obstacle is the cost involved. Investing in a modern Generation III reactor is simply too expensive to make private sector involvement profitable. Meanwhile, a public-private partnership arrangement may not be feasible given limited government resources. If the committee will be convinced of the advantages of nuclear energy, there are at least two possible options to cost-effectively incorporate it in the Philippines. Both are not mutually exclusive.

The first is the revival of the BNPP. In 2009, Korea Electric Power conducted a feasibility study on the possible revival of the BNPP. The estimated cost at that time to make the BNPP operable was US 1 B. This is much lower than the option of building a new nuclearreactor. In May 2018, it was reported that Rosatom (the Russian state nuclear enterprise) revealed that its analysis of the BNPP showed that it was, in fact, not only possible but safe to refurbish and restart the plant. The assessment was conducted in August 2017. However, in April 2018, Russian Ambassador Igor Khovaev was reported as saying he believes the BNPP is beyond revival (*Cabato 2018*). The Philippine government can engage the services of expert consultants to make an objective and unequivocal recommendation on this matter.

The other option is to look into small modular reactors (SMR), which is the emerging technology in nuclear energy (*Vujić et al. 2012*). SMRs are nuclear reactors whose capacity to generate electricity is less than 300 MW per module. These are very useful in the process of distributed generation, particularly for countries or regions with relatively large chunks of off-grid areas. SMRs can also power large industrial complexes. Estimates indicate that the LCOE of SMRs could be competitive with larger nuclear units and with other dispatchable generating technologies (*IEA 2019*). SMRs have not yet been mainstreamed in the global energy market. However, they are already on the radar of the DOE (*Domingo 2019*). Hence, this option can readily be considered by the NEP-IAC.

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