

Assessment of costs of nuclear power in Bangladesh

Islam Md. Shafiqul¹, Tanvir Hassan Bhuiyan¹

¹ Department of Nuclear Engineering, University of Dhaka, Dhaka-1000, Bangladesh

Corresponding author: Islam Md. Shafiqul (msislam@du.ac.bd)

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Abstract

Financing and economic risks are two of the major challenges facing by the nuclear industry today for the construction of a new build Gen III+ or an advanced Gen IV nuclear power plant (NPP). Prediction of economics and financial aspects of an NPP always remains uncertain as these are heavily dependent on investment costs, construction time, licensing and regulation, operation and maintenance (O&M) costs, fuel costs, financing costs, plant capacity factor (PCF), etc. Such uncertainty in accurately predicting the risk of financing and economics limits the growth of the nuclear industry. Furthermore, global high-trend construction costs of NPPs lack confidence amongst manufacturers and builders. This paper attempts for modeling the costs of the twin under construction VVER-1200 model Gen III+ reactors at Rooppur in Bangladesh based on techno-economic and financial data, and some assumptions. To calculate the levelized unit electricity cost (LUEC), net present value (NPV), internal rate of return (IRR), and payback period (PBP), nine scenarios are modeled in the FINPLAN modeling tool given the plant technical data, investment costs, financial terms & conditions, global benchmarked operation & maintenance (O&M) costs and fuel costs, PCFs of 50–90%, and a fixed discount rate of 10%. The study finds that the estimations of LUECs of the Rooppur NPP project are in the range of 43.8–82.5 \$/MWh of which are lower than for coal, oil, and renewable energy sources. The annual rate of return of the project is found in the range of 13–20%. The PBP is within 7–8 years after the start of commercial operation. Cost sensitivity analysis is performed by taking a large variation of O&M costs, fuel costs, and PCFs. The results show favorable economic situations with regard to the country's other power sources and are expected to be competitive with global NPPs projects. Only the competitive NPP projects can contribute to a sustainable economic, social, environmental, scientific, and technological developments for both NPP importing and exporting countries.

Keywords

Economic and financial indicators, Rooppur NPP project, VVER-1200 Gen III+ reactor, LUEC, Cost sensitivity, Cost competitiveness

1. Introduction

Bangladesh aims to be a middle income and developed country by 2030. In the last decade, the country has made remarkable progress in the socio-economic development with an average 6.5% annual gross domestic product growth rate (WB 2020). However, the generation of

electricity and its uninterrupted power supply is the prerequisite for ensuring accelerated economic growth. To keep pace with the current development growth, demand for electricity is found to be increasing at a rate of 10% each year (Bazlul and Iftekher 2017). The Power System Master Plan (PSMP) of the Ministry of Power, Energy, and Mineral Resources is the roadmap of the country's

power and energy development strategy. According to the PSMP (2016), Bangladesh has planned to increase its power generation from 22GW to 60GW within 2041. Currently, Bangladesh's power generation mix relies on domestic gas (62%) which has a reserve for only 10–15 years at the current consumption rate, oil (29.8%), a small portion of renewables including hydro (1.75%), coal (1.9%), and imported electricity (4.55%) from India (BPDB 2018–2019, Huq et al. 2018). Considering future energy security for more industrialization, rapid economic growth, and global commitments towards sustainable development goals, PSMP (2016) has adopted a fuel diversification policy, including imported coal, liquefied natural gas (LNG), and nuclear fuel. As the prospects of renewable energy technology are limited, the country's future energy security will primarily rely on coal, LNG, and nuclear-based plants.

The idea of a nuclear power program for Bangladesh has a long history dating back to 1961. Pakistan Atomic Energy Commission had selected the Rooppur site, 160 km away from the capital Dhaka of Bangladesh in 1963 out of 20 possible sites. During the 1960s, several international companies conducted feasibility studies but all the initiatives went in vein due to political unrest. After the independence in 1971, the implementation of an NPP got stuck until 2009 due to the lack of funds and political will. The prevailing power deficit across the country compelled the government to take a firm political decision for reviving the Rooppur NPP project in 2009 (Ashraf and Islam 2018, Akbar 2017).

In 2011, Bangladesh signed an intergovernmental agreement (IGA) with the Russian Federation for the construction of the necessary infrastructure for the country's first NPP at Rooppur site consisting of two VVER type nuclear reactors (IGA 2011). Subsequent to the IGA and the general contract agreements, Russian State Atomic Energy Corporation-Rosatom and Bangladesh Atomic Energy Commission signed a financial contract in 2015 with amounts to the United States Dollar (USD) 12.65 billion for the design, construction, and supply of twin VVER-1200 model Gen III+ nuclear reactors with 1200MWe electric capacity each, including the first few years' fresh fuel supply with Russia financing 90% of the total investment cost at an interest rate of *libor* plus 1.75%, capped at 4%, repayable in 28 years with 10 years' grace period (WNA 2020). As O&M costs, fuel costs, and other costs are related to the reactor startup, these are not included in the general contract/agreements. NPPs require high investment, intensive infrastructure, and lead to skepticism with regard to financial and economic viability. The cost of electricity produced by an NPP should be competitive against gas, coal, and oil-fired power plants.

Most of the studies find that operating NPPs have acknowledged cost-competitive with other alternatives. The reasons behind cost-competitive are due to low O&M costs, fuel costs, high production rate, long economic lifetime, and low CO₂ emission electricity supply (Locatelli and Mancini 2010, Carelli 2010, Lovering et al. 2016,

WNA 2017). However, some other studies show that construction of an NPP is a risky venture and will get lost with alternatives if constructions delays, cost overruns, regulatory uncertainty, poor performance (fuel cycles) unregulated power market, and accidents are not properly addressed (Thomas et al. 2007, Ishrak 2015a). In order to be cost-competitive, construction costs and time of NPPs should be cut at least 25% from the existing estimates (MIT 2003). No scholarly articles are found focusing on economic and financial analyses against a particular NPP project. To the authors' knowledge, a few comprehensive reports on the economic aspects of NPP projects are available online; for example Hungary, and Belarus (Paks II 2015, IAEA/INPRO 2013). It is imperative to study the economic and financial feasibility of an NPP project to perceive its potential risk.

The financial and economic viability of the country's first NPP has constantly been under scrutiny by researchers, policymakers, and society. Part of the society is constantly pressing the government to stop construction of the Rooppur NPP as it needs high capital investment, intensive infrastructure, and brings expensive unit electricity cost with respect to other available power sources (Rahman, 2016a; Ishrak, 2015a). However, no such elaborative studies are available publicly in this regard except a few limited ones. Sieed et al. (2015) calculate the LUEC of 9.48 cents/kWh by considering overnight construction costs of 5000\$/kWe, plant lifetime 60-year, and PCF of 90% using INPRO methodology. They also find that LUEC from nuclear power is a bit higher than the gas and coal-based power plants. Their economic feasibility studies find supportive towards the viability of the project in terms of long-term economic contributions. While Rahman (2016) in his hand calculation considering total capital costs including the costs of pre-project activities of 13.20 billion USD with a 4% simple interest rate for 28-year repayment period, fixed O&M costs of 0.2\$/MWe-yr, variable O&M costs of 2.4\$/MWh, fuel costs of 0.62 cents/kWh, decommissioning costs of 1.5 billion USD, PCFs of 65–85%, and a plant economic lifetime of 60-year shows that LUECs at ideal to realistic conditions are found as 9 and 12 cents/kWh respectively. He also argues that the project is costly compared to other power generating sources. Bazlul and Iftekher (2017) conduct financial and economic feasibility studies of the project by considering only one set of optimistic parameters, such as a PCF of 93%, a plant lifetime of 50-year, and a discount rate of 5%. They assume the LUEC of 3.5 cents/kWh for finding the benefit-cost ratio and other social and economic aspects of the project. Amimul et al. (2014) describe the necessity of the Rooppur NPP project with its basic safety, security, and waste management features of the selected modern VVER-1200 model nuclear reactor technology without touching the economic aspects of the project.

This paper differs from the existing literature, because nobody has made a detailed cost-economic analysis considering the lifecycle costs of the country's first NPP pro-

ject so far, or at least the authors could not find any that would have been publicly available. This paper fills this gap in knowledge estimating the NPV, IRR, and LUEC under different postulated scenarios for depicting the financial and economic aspects of the Rooppur NPP project. The calculated cost-economic analyses could be used as a basis for whether the nuclear is more/less expensive than a baseload gas or a coal-fired plant.

Furthermore, the findings are compared with the cost data of the global operating as well as under construction similar NPPs and give confidence in building modern large size Gen III/III+ reactors economically. In order to calculate the NPV, IRR, and LUEC parameters, the study explores investment costs and its terms & conditions, O&M costs, fuel costs, PCF, and decommissioning costs including waste management at the end of its economic lifecycle (WNA 2020, Paks II 2015). The study uses the FINPLAN modeling tool which is developed by the International Atomic Energy Agency (IAEA) to clarify the feasibility of electricity generation projects by computing important financial and economic indicators (IAEA 2009). Further details on the FINPLAN modeling tool can be found in Section 4.1. The rest of the paper is structured as follows: section 2 presents the literature review; section 3 describes the indicators of economic and financial performances of NPPs; section 4 provides a brief introduction to FINPLAN modeling tool and input data; section 5 narrates the results and discussion based on nine postulated scenarios and finally, section 6 concludes the paper.

2. Literature review

In the PSMP-2010, it was then decided that 10% of the total electricity generation will come from NPPs by 2021 and 2030, which are 2000MWe and 4000MWe respectively. However, in the new PSMP-2016, goals for power generation from NPPs remain the same as in the PSMP-2010. Due to the depletion of domestic gas reserves and no discovery of new gas fields as of August 2020, imported LNG, coal, and nuclear are considered three of the best options for baseload electricity generation for future energy security, environmental protection, and sustainable economy. According to the PSMP-2016, the government plans to add 2,400MWe electricity from NPPs at Rooppur (unit 3 & 4), and another 2400MWe electricity from a new NPP site in the southern part of the country. Rooppur NPP is the largest project ever undertaken by the country in terms of cost, infrastructure, technical complexity, and risk profile. Some mixed reactions are found from scholarly articles about the feasibility of the Rooppur NPP project.

Reza et al. (2014) raise the question about the affordability of the rapid increase in electricity generation costs with gas, oil, coal, and renewables. Considering public affordability and to gain public popularity, the government provides a substantial amount of subsidies every year to the electricity generation companies. They ex-

pect that nuclear can be a good option for maintaining a steady electricity price. Ishraq (2015b) raises the question of whether it is worthy to spend huge money and take environmental risks to build the Rooppur NPP for generating only 5% electricity to the national grid. Sakib (2015) studies support the Rooppur NPP project although it is a much-talked issue in the country. Alam et al. (2019) emphasize the necessity for the construction of NPPs as an alternative to fossil fuels for energy security and the socio-economic development of the countries. Ahmed (2014) advocates, Bangladesh should go nuclear for her energy security and sustainable development. Mollah et al. (2015) rationalize the government's decision for the implementation of the Rooppur NPP project to optimize the country's energy mix to get rid of the chronic power crisis. Saha et al. (2018) give logical explanations for the development of a nuclear power program in Bangladesh and expecting a successful implementation of the Rooppur NPP project. Matin (2015) estimates 4,875 \$/kWe as probable capital costs of the VVER-1200 model Gen III reactor for the Rooppur NPP project and compares with the costs of the global NPPs. He claims that this could be a high capital cost in comparison with the similar model reactors to be built in Belarus, Turkey, China, India, and Vietnam. Rahman (2016b) criticizes the government for frequent change in fixing the total price tag from \$2 billion to \$12.65 billion between the VVER-1000 and 1200 model reactors. Although the government has fixed the \$12.65 billion capital cost of the 2400MWe capacity VVER-1200 model twin reactors, he says, "the sky is the limit for the final cost".

Bangladesh power development board (BPDB) is the only government electric utility, who is the single buyer to purchase electricity from other public and private utilities. The price of electricity depends on not only the type of fuel but also the type of utility such as public or private, or imported ones. The country has only one government-owned power transmission company. The electricity to be generated from the Rooppur NPP will be sold to the BPDB.

Barkatullah and Ahmed (2017) investigate the existing challenges to finance NPPs and find no such unique model. Historical record of construction costs, past success and failure experiences teach us that the projected average lifecycle costs of electricity are always underestimating than the real cost scenarios. High investment costs should be considered in financial and economic studies (Hultman et al. 2007).

Construction of some modern reactors are abandoned or much delayed from the schedule due to cost overruns. Olkiluoto-3 plant in Finland was thought to have considered a creative financing model, is now suffering from both cost overruns and construction delays (IAEA 2018). Generation costs depend on country specific, region specific, size of a reactor, era, experience, and safety features (Loving et al. 2016). People may think that today's modern large light water reactors (Gen III/III+) can be built more cheaply. Meanwhile, some other people may also

think, small modular reactors will be more promising in cost economics. However, these are two sides of the same coin (Mignacca and Locatelli 2020, Boarin et al. 2017, Locatelli and Mancini 2010, Carelli et al. 2010). Krautmann and Solow (1988) realize that predicting the economics of the future nuclear industry is extremely risky. They find that large size reactors do not guarantee much output in the long run cost function. However, constructions of multiple units at a single site are economically attractive. Despite the construction costs going up a substantial amount due to the Three Mile Island, Chernobyl, and Fukushima accidents as well as bankruptcy & restructuring of giant nuclear companies, 4 newcomers i.e. Bangladesh, Belarus, Turkey, and United Arab Emirates have broken ground on new reactors out of 54 reactors under construction in 19 countries (IAEA/PRIS 2020). However, about 30 newcomer countries especially in the developing world are actively considering building NPPs (WNA 2020).

3. Economic and financial performances of NPPs

Before discussing the economic and financial performances of NPPs, it is relevant to differentiate between economic and financial studies. Economic studies focus on the efficiency in production, distribution, and consumption of goods and services, taxes, inflation, exchange rates, costs, prices, etc (Zweifel et al. 2017). LUEC is a common indicator used in economic studies. The economic studies do not consider debt or equity. On the other hand, financial studies are based on the management of funds, financial resources, debt, equity, risks, etc. NPV, IRR, and PBP are the common indicators used in financial studies (Brigham and Ehrhardt 2011, Besley and Brigham 2016). Here is given a brief purview of these indicators.

3.1 Investment costs

Construction of an NPP is highly capital intensive and have a long construction period. Investment costs include cost of site preparation, construction, manufacture, and commissioning of reactors. Fixing investment costs mainly depend on site characteristics, type of technology with safety features, manpower, materials, regulatory requirements, and localization of technology. It is the major percentage (70%) of the lifecycle costs of an NPP and major decision making matrices for taking a project by the policymakers. The cost of capital of an NPP is a function of the financial risk associated with the project investment (Carelli and Ingersoll 2014, Barkatullah and Ahmed 2011, Xoubi 2019, IAEA 2017).

3.2 Operation & Maintenance (O&M) costs

O&M activities refer to the day-to-day operations of the plant. The assumption of O&M costs is a very important

factor to estimate the NPV and IRR accurately. Early on, low O&M costs used to be considered in nuclear economics. But this assumption was proven wrong in the late 1980s and early 1990s when a small number of US NPPs were retired for the high O&M costs compared with gas power plants (EIA 1994). This happened due to the rise of uranium prices in the global market. For economic analysis, O&M costs can be assumed from the OECD/NEA (2005, 2015) or globally benchmarked data (Paks II 2015). O&M costs vary with country specific, region specific, size of a reactor, efficiency of the plant, safety features, and its major components comprising staff costs, material costs, contractor services, and taxes, etc. It owes about 15% of the lifecycle costs (IAEA 2017).

3.3 Fuel costs

The fuel cost refers to mining, conversion, enrichment, and fabrication, which is called the front-end fuel cycle. Most of the NPPs operating countries do not have their own fuel cycle capabilities. The Aszódi report (2014) mentions fuel costs as one of the key variable costs in the formulation of the project's LUEC and it is about 15% of the lifecycle costs (IAEA 2017). Fuel costs can be assumed from the globally benchmarked data. Although the LUEC values of NPPs are relatively insensitive to changes in fuel prices as it is almost stable in the international market compared with fossil fuels. A strategic approach needs to be developed for a fuel cycle policy. In order to have a more competitive and secured fuel supply management, an owner-operator can contract with multiple vendors and of course need to be made long term agreements.

3.4 Decommissioning including waste management costs

The decommissioning costs include all costs related to the plant's shutdown to the dismantling of nuclear and non-nuclear structures, systems, and components phase by phase. It also includes radioactive waste management and disposal including spent fuels that will arise during the operation lifetime and dismantling of the plant after its service life. According to the World Nuclear Association data, the decommissioning cost is assumed to be about 9–15% of the total capital cost of an NPP (OECD/NEA 2016). The plant owner has to accumulate this decommissioning fund during plant operation.

3.5 Levelized unit electricity cost (LUEC)

The LUEC/levelized cost of electricity (LCOE) is equivalent to the generation costs of electricity at the plant level that would have to be paid by the consumers to repay exactly all costs for investment, year-wise O&M costs, fuel costs, and decommissioning costs with a proper discount rate and without considering profits. It can be said in another way that LUEC is the minimum average busbar costs/selling price in which an owner-operator

would precisely break-even on the project after paying all necessary expenses over its operating lifetime. This economic indicator is called a lifecycle costs of an NPP and is expressed in energy currency (\$/kWh) (Mignacca and Locatelli 2020). Equation (1) can be used to calculate the LUEC without considering the cost of carbon (IAEA/NES 2018).

$$LUEC = \frac{\sum_{t=0}^{t_{life}} \frac{(Investment\ cost_t + O\ \&\ M\ cost_t + Fuel\ cost_t + Decommissioning\ cost_t)}{(1+r)^t}}{\sum_{t=1}^{t_{life}} \frac{(Annual\ electricity\ generation)}{(1+r)^t}} \quad (1)$$

Where t ; the expected lifetime of the plant (year);

t_c : the duration of construction (year);

r : annual discount rate (%);

Annual electricity generation in MWh

Here it is worthy to note that LUEC is not a complete and absolute method of assessing the economic benefits of an electricity generating source because it excludes the true reflection of market realities and network costs of a power system. In the case of nuclear power generation, the LUEC is strongly dependent on investment costs, O&M costs, and fuel costs (Lovering et al. 2016, Barkatullah 2011, Mignacca and Locatelli 2020).

3.6 Discount rate

The discount rate is possibly one of the most critical parameters of the economic and financial analyses of a power generating plant. It varies by country, technology, and finance specifics. LUEC is sensitive to change in the discount rate i.e. the interest rate used to calculate the present value of future cash flows. The choice of the discount rate depends on a number of factors such as, competitors, power market policy, and investor (who determine the required rate of return). In many review studies, the discount rate was arbitrarily chosen as 5% and 10% (Larsson, 2014). British economist Dimson (1989) shows in his study that the discount rate for a new NPP after tax should be 11%. In an open electricity market, building and operating an NPP is risky as cost recovery is not guaranteed. In this context, for evaluating an NPP project profitability, the energy information administration (EIA)/USDOE (1994) is proposed to take a discount rate of 10% in real terms (the 3% risk-free return plus a 7% risk premium) (IAEA/NES 2018).

3.7 Plant capacity factor (PCF)

Uncertainty between the plant's idealized and realized capacity factor is a very important issue for economic and financial analyses of an NPP project (Yangbo and John, 2010). It indicates the operating performance of a plant under many O&M challenges. Usually, a plant running at a higher PCF incurs a lower unit production cost compared to a plant running at a lower PCF. The global average PCF for NPPs is about 85% (Paks II, 205). However, it took much effort to achieve such a high average PCF.

3.8 Net present value (NPV)

The NPV is the difference between the present value of net cash inflow(revenues) and net cash outflow (expenditures). It is used in capital budgeting to analyze the profitability of an investment or project and is expressed in [\$]. For an investment project, raising the discount rate tends to reduce the NPV. This parameter is multiplication between net cash flow and discount factor (Mignacca and Locatelli, 2020). Equation (2) can be used to calculate the NPV;

$$NPV = \sum_{t=1}^T \frac{C_t}{(1+r)^t} + C_0 \quad (2)$$

Where, C_t = net cash flow during the periods (\$) t , C_0 = total initial investment costs (\$), r = discount rate, $(1+r)^t$ = discount factor, and t = number of time periods.

NPV is used as an indicator for viability of a project as follow;

NPV = positive value (+), Project feasible /can be accepted, higher NPV is better;

NPV = negative value (-), Project not feasible /cannot be accepted;

NPV = zero (0), neutral value/break-even (no profit or no loss).

3.9 Internal rate of return (IRR)

The IRR is the discount rate at which the NPV of net cash flow (both positive or negative) from a project or investment equals to zero. It is also used to evaluate the viability of a project or investment and is expressed in dimensionless indicator [%]. When the IRR of a new project exceeds its required rate of return, the project is desirable. On the other hand, if IRR falls below the required rate of return, the project is not financially desirable (Mignacca and Locatelli, 2020). IRR can be calculated using Equation (3).

$$NPV = 0 = C_0 + \frac{C_1}{(1+IRR)^1} + \frac{C_2}{(1+IRR)^2} + \frac{C_3}{(1+IRR)^3} + \dots + \frac{C_n}{(1+IRR)^n} \quad (3)$$

Where C_0 = total initial investment costs (\$), C_1, \dots, C_n equals the net cash flow during the periods 1, 2, 3, ... n, respectively.

Feasibility criteria of IRR gives indication as follow;

IRR > wanted discount rate (r), project feasible /accepted;

IRR < wanted discount rate (r), project not feasible /not accepted;

IRR = wanted discount rate (r), project not feasible /not accepted.

3.10 Payback period (PBP)

The PBP is a duration needed to return the investment cost, which is calculated from net cash flow. Net cash flow is a difference between the revenue and expenditures every year. PBP is an indicator of how many years are

needed for the project to cover the total investment costs. Equation (4) can be used to calculate the PBP.

$$\sum_{t=1}^{t=PBP} B = C_0 \quad (4)$$

Where t = time (yr), PBP = Payback period (yr), B = benefit of profit (\$), C_0 = total investment costs (\$)

If the projects were constructed within the 5–6 years, the payback period would be usually within 7–9 years (Paks II 2015).

Now it is understood from the theoretical discussions that the LUEC, NPV, IRR, and PBP indicators are used to find out the competitiveness of an NPP project with other power generating sources in order to ensure the profitability. Kharitonov and Kosterin (2017) develop analytical relationships between the investment performance criteria (LUEC, NPV, IRR, discounted PBP, discounted costs) and basic engineering - economic parameters (capital costs, annual operating costs, annual revenue, construction duration, operating lifetime) of an NPP for measuring the profitability and competitiveness at the microeconomic level.

OECD/NEA (2007) predicts the LUECs and other financial risks of the Gen IV reactors with other energy sources and finds highly competitive in the international energy markets. Lucheroni and Mari (2014) suggest careful use of LCOE when someone estimates the performances of the lifecycle costs of a new NPP and compare it with other power sources as these are not homogeneous in nature. LCOE value for NPPs works as an asset to reduce the dynamics of fossil fuels and carbon prices in the volatile power markets (Mari, 2014). While calculating the LUEC, NPV, and IRR for modeling the economics of a new NPP, these indicators are found to be heavily dependent on realized input data. Winkler and Streit (2008) find the economic profitability of the three NPP projects at Beznau, Muhlenberg, and Niederamt in Switzerland. The LUEC of the Swiss operating NPPs is about 2.4 cents/kWh. IAEA/INPRO (2013) finds the economic viability of the Belarus NPP project by evaluating the LUEC, IRR, return of investment, and investment volume indicators. Paks II NPP project of Hungary is also found economically viable by evaluating LCOE, NPV, IRR, and PBP parameters (Paks II 2015).

4. Calculation tool and input data

4.1 FINPLAN model

The model for Financial Analysis of Electric Sector Expansion Plans (FINPLAN) is a world-wide recognized financial modeling tool, which is used for financial analysis of electricity generation projects (IAEA 2009). Inputs for the FINPLAN modeling tool were divided into four headings; cost related data, technical data, economic and fiscal parameters, and financial data. Cost-related data included investments, O&M costs, fuel costs, and decommissioning costs. Technical data involved plant's power generation capacity, construction period, commercial operational year, plant life-

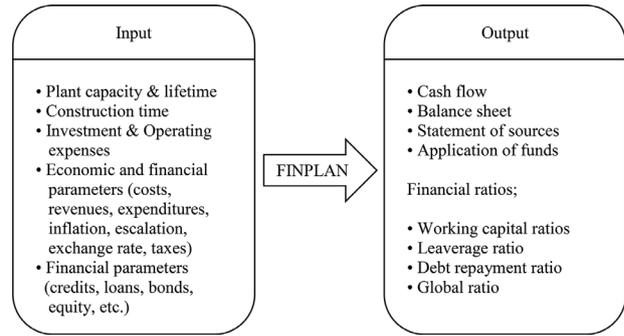


Figure 1. Data processing systems.

time, and PCF. Economic parameters referred to revenues, expenditures, inflation, exchange rates, taxes, etc. Financial parameters included credits, loans, bonds, and equity, etc. Figure 1 shows how the FINPLAN modeling tool converts from input into output parameters for each year.

The model provides outputs as cash flows, balance sheet, financial ratios, NPV, IRR, etc. Foreign currency, exchange rate, and inflation rate were considered as the important parameters in financial analysis. As such, the FINPLAN modeling tool allows options for considering one or multiple foreign currencies in the financial analysis. In the data on a product sale/purchase, the FINPLAN modeling tool needed the number of units of electrical energy to be sold per annum and the unit electricity selling price data over the plant's economic lifetime. Nine different postulated scenarios were created for the calculation of financial and economic analysis of the Rooppur NPP project. Based on the fixed cost financial contract, plant data, general data, and some assumptions on O&M costs, fuel costs, decommissioning costs, and PCFs, etc. LUEC, NPV, IRR, and PBP were calculated for each case study.

4.2 Technical, economic, and financial data

Nine case studies were modeled based on the plant's technical, economic, financial data, and a few assumptions for calculating the financial and economic aspects of the Rooppur NPP project. In this regard, Table 1 shows a summary of some key plant technical, financial, and economic input data. Brief descriptions of these data are given in the following sections.

4.2.1 Plant technical data

According to Table 1 and Figure 2, the Rooppur NPP project comprises the twin unit of VVER-1200 model reactors with 1200MWe electric capacity each. In this calculation, the construction time was taken as 6-year while the plant economic lifetime was considered as 60-year. The first commercial operations of both units are expected to be in 2023 and 2024 respectively.

The construction, commissioning, and commercial operation schedule of the unit-1 and unit-2 of VVER-1200MWe capacity of each reactor are shown in Figure 2. Schedule test operation of the unit-1 is going to be held in 2022 and the unit-2 in the later year. The nuclear power

Table 1. Some key plant technical, economic, and financial data at nine different postulated cases considering low and high values of O&M costs and fuel costs (WNA 2020, Paks II 2015).

Item	Variable	Case-1	Case-2	Case-3	Case-4
Plant technical data	Unit-wise plant capacity	1200MW _e × 2 unit = 2400MWe			
	Construction period	6-year			
	First commercial operation year	Unit 1–2023 and Unit 2–2024			
	Plant lifetime	60-year (2022/2023 to 2081/2082)			
Investment costs and its terms and conditions	Plant capacity factor (PCF)	75%	80%	85%	90%
	United States Dollar (USD)	11.4 billion			
	Bangladeshi taka (BDT)	219.2 billion			
	Interest rate	4%			
Inflation rate	Repayment period	28 years			
	USD	Steady rate 2% / year			
Tax rate	BDT	Steady rate 6% / year			
	Steady rate	25%			
Currency exchange rate	Exchange rate reflects the inflation rate	80 BDT per USD			
Depreciation	Linear	60 Years			
O & M costs (Low case)	From 2022	123 Million USD per year (7.82 \$/MWh)	131.5 Million USD per year (7.82 \$/MWh)	139.7 Million USD per year (7.82 \$/MWh)	148 Million USD per year (7.82 \$/MWh)
Fuel costs (Low case)	From 2022	70.95 Million USD per year (4.5 \$/MWh)	75.7 Million USD per year (4.5 \$/MWh)	80.4 Million USD per year (4.5 \$/MWh)	85.1 Million USD per year (4.5 \$/MWh)
O & M costs (High case)	From 2022	228.6 Million USD per year (14.5 \$/MWh)	243.8 Million USD per year (14.5 \$/MWh)	259 Million USD per year (14.5 \$/MWh)	274.4 Million USD per year (14.5 \$/MWh)
	From 2022	176.6 Million USD per year (11.2 \$/MWh)	188.4 Million USD per year (11.2 \$/MWh)	200.1 Million USD per year (11.2 \$/MWh)	211.9 Million USD per year (11.2 \$/MWh)
	From 2022	14.5 \$/MWh	11.2 \$/MWh	Plant capacity factor (Worst)	50%
	Decommissioning costs	Fund starting from 2030	1.0 billion USD		
Discount rate		10%			

company of Bangladesh limited is a public limited one who is the operator of the Rooppur NPP.

4.2.2 Economic and financial data

4.2.2.1 Investment costs and its terms & conditions

According to the financial contract, Russia has agreed to provide 11.38 billion USD as a State credit with an interest rate of Libor plus 1.75% and capped at 4%. This covers 90% of the total investment costs of 12.65 billion USD. This State credit is to be repaid over a period of 28 years. The government of Bangladesh provides the remaining 10% i.e. USD 1.27 billion of the total investment costs (WNA 2020, Akbar 2017, Rahman 2016). The inflation rate was taken to be changed at a steady rate of 6% per year against the local currency (Bangladeshi Taka-BDT; 1USD = 80 BDT). For the USD foreign currency, the inflation rate changes at a steady rate of 2% per year. Among the four available depreciation calculation methods, linear depreciation was chosen to calculate the total depreciation over the depreciable life of the plant for simplicity. In this calculation, the depreciation time was considered over the total economic life of the plant e.g. 60-year.

4.2.2.2 Operation & Maintenance (O& M) costs

In the case of the Rooppur NPP project, it was not publicly available to get the actual data of O&M as well as fuel costs from the financial agreement between the Russian Federation and Bangladesh (Akbar 2017). Under this situation, we searched for global benchmarked data. Table 2 shows the global NPP O&M costs and fuel costs data used in different economic studies. Under different studies, the O&M costs and fuel costs data are not varied except OECD/NEA (2005). In the OECD/NEA (2005) studies, a high variation is found in both O&M and fuel costs data. In the Hungarian economic study on the Paks II NPP project, they took the global average benchmarked data (Paks II 2015).

In line with the global cost trend data, in our analysis, assumptions of O&M costs for low and high case scenarios were considered as 7.82\$/MWh and 14.5\$/MWh respectively. The variation of O&M costs from low to high case

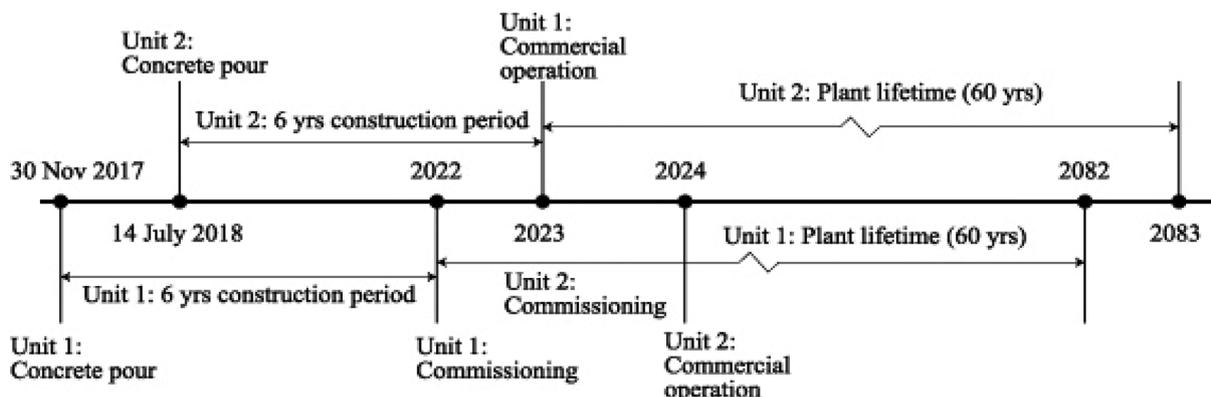


Figure 2. Construction, commissioning, and commercial operation schedule of the twin VVER-1200MWe model reactors at Rooppur.

Table 2. NPP O&M costs and fuel costs data (Thomas et al. 2007, Locatelli and Mancini 2010).

Name of the study	O&M cost (\$/MWh)	Fuel cost (\$/MWh)
MIT (2003)	12.34	4.82
The Royal Academy of Engg. (2004)	14.58	11.22
The University of Chicago (2004)	8.98	4.49
Canadian Nuclear Association (2004)	7.86	4.49
OECD/NEA(2005)	11.22–29.23 (average=20.2)	4.49–19 (average=11.74)
UK Energy Review (2006)	12.9	6.51
Global high case (Paks II, 2015)	18.4	7.85
Global low case (Paks-II, 2015)	7.52	5.27
Global average (Paks-II, 2015)	12.79	6.28
This study (Rooppur NPP project)		
High case	14.5	11.2
Low case	7.82	4.5

scenarios is about 45%. The assumed O&M costs data for the high case scenario is close to the global average data.

4.2.2.3 Fuel costs

In the case of fuel costs, the OECD/NEA's (2005) low and high benchmarked data are 4.49\$/MWh and 19\$/MWh respectively while the global average data is 6.28\$/MWh. In this analysis, a low and a high value of fuel costs were assumed as 4.5\$/MWh and 11.2\$/MWh respectively. The variation in fuel costs from low to high cases is at about 40%. The high-end fuel cost is about double to the global average data but close to the OECD/NEA average data. Russia will provide the up-to-date efficient fuels at the international market price for the entire operating lifetime of the two units of the Rooppur NPP according to the fuel supply contract (TVEL 2019). The fuel reloading cycle will recommence in every 18 months.

4.2.2.4 Decommissioning costs

In this study, a fund amounting to 1 billion USD which is equivalent to 9%, was considered for decommissioning cost in order to dismantle the two units after the end of its 60-year economic service life.

4.2.2.5 Discount rate

The discount rate was set to 10% for the nine case studies where the foreign loan interest rate is to be not more than 4%. Reasons for fixing a high discount rate for a developing economic country like Bangladesh are manifold;

- (i) Quick return of investment (shorter payback period) for higher LUECs
- (ii) Operational uncertainty (a high gap between demand-supply)
- (iii) High inflation rate
- (iv) Socio-political uncertainty and natural calamities prone country
- (v) Country's high infrastructure development cost than the neighboring countries

- (vi) Possibility of high opportunity costs of 10% government fund
- (vii) Possible accidents and liability.

4.2.2.6 Plant capacity factor (PCF)

In this study, four different PCFs were considered as 75, 80, 85, and 90%. However, the design PCF of the VVER-1200 is 90% and the global average PCF is 85% (Paks II 2015). It is noteworthy that the average PCF of fossil fuel-based power plants is below 50% in Bangladesh (BPDB 2018–2019). The reasons for this low PCF are due to interrupted primary fuel supply, grid instability, insufficient grid network, poor management, and less consumption of electricity during the lean period. In such a situation, Rooppur NPP may not be an exceptional one. For this, a 50% PCF was considered in a worst-case scenario to predict a high perceived risk.

5. Results and discussion

5.1 Case study 1 to 4

The variation of NPV and IRR are plotted by varying the selling price of electricity at nine different postulated scenarios for twin units. Figures 3 and 4 depict the variation of NPV and IRR with the selling price of electricity at low O&M costs and fuel costs with four different PCFs of 75, 80, 85, and 90%. These curves are plotted by taking a gradual increment in each step of 0.125 cents/kWh (BDT: 0.1 taka/kWh). It is found in Fig. 3 that for the four case studies of 1 to 4, LUEC values stand to 4.95, 4.75, 4.60, 4.37 cents/kWh at which NPV=0. It is also seen above or below those LUEC values, NPV becomes positive or negative. At NPV=0, the total revenue (cash inflows) is equal to the total expenditures (cash outflows) of which is the break-even or minimum selling price of electricity of the project. When the selling price of electricity drops below those LUEC points, NPV becomes negative, which results in a net loss of the project. From the IRR perspective, as shown in Fig.4, at NPV=0, the threshold IRR stands to 14.30, 17.67, 17.00, and 13.24% at four case studies of 1–4 respectively which is higher than the discount rate (10%) of the project. With the increase in the selling price of electricity as well as the PCF, a small variation of IRR is found for all the cases. However, it reaches up to 20%. On the other hand, below those LUEC values, IRR becomes less than the discount rate (10%) which is risky for the project. It can be worth mentioned here that for high investment and long operating lifetime of an NPP, a higher IRR is not expected but an attractive NPV is expected steadily over a long time of the plant. Among the four case studies, case study-4 is found better in terms of the selling price of electricity where LUEC stands to 4.37 cents/kWh at a high PCF of 90% and low O&M costs and fuel costs. However, such a high PCF matters only 12% on the LUECs. In this ana-

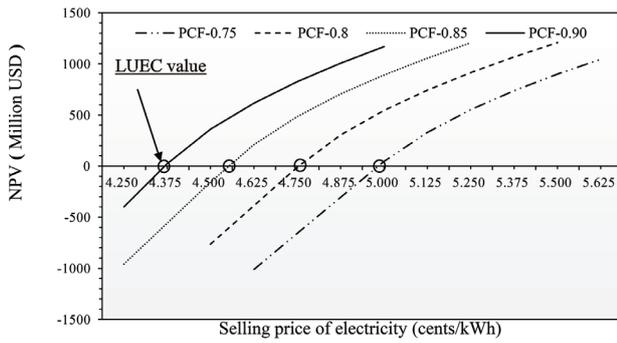


Figure 3. Variation of NPV with selling price of electricity considering low O&M cost-7.82\$/MWh and fuel cost-4.50\$/MWh, discount rate-10%, and PCFs-75, 80, 85, and 90% (Case 1 to 4).

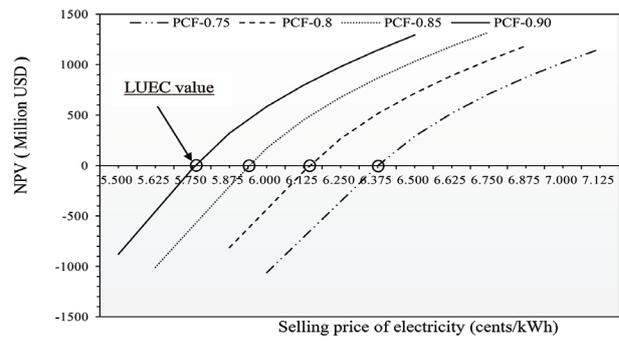


Figure 5. Variation of NPV with selling price of electricity considering high O&M costs-14.5\$/MWh and fuel costs-11.2\$/MWh, discount rate-10% and PCFs-75, 80, 85, and 90% (Case 5 to 8).

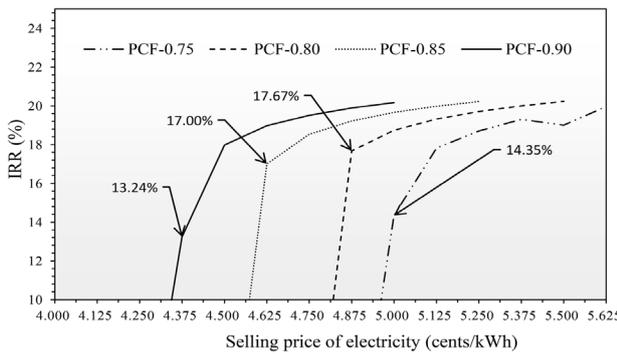


Figure 4. Variation of IRR with selling price of electricity considering low O&M costs-7.82\$/MWh and fuel costs-4.50\$/MWh, discount rate-10% and PCFs-75, 80, 85, and 90% (Case 1 to 4).

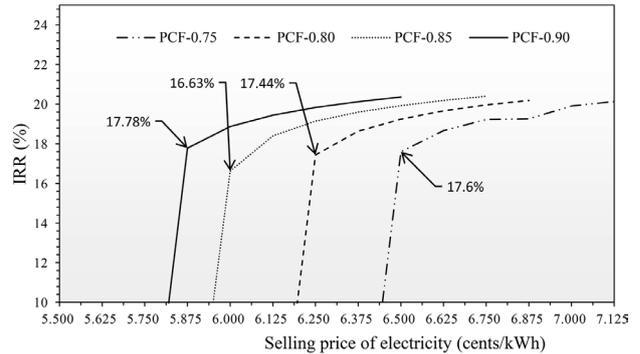


Figure 6. Variation of IRR with selling price of electricity considering high O&M costs-14.5\$/MWh and fuel costs-11.2\$/MWh, discount rate-10% and PCFs-75, 80, 85, and 90% (Case 5 to 8).

lysis, the relationship between NPV vs selling price of electricity and IRR vs selling price of electricity appear non-linearity as the inflation rate for both foreign and local parts of 2% and 6% respectively in which is far from the discount rate (10%).

5.2 Case study 5 to 8

The case studies of 5–8 (Figures 5 and 6) are drawn to see the variation of NPV and IRR with a selling price of electricity considering a high O&M cost of 14.5\$/MWh and a high fuel cost of 11.2\$/MWh. Graphs NPV vs. selling price of electricity (Fig. 5) and IRR vs. selling price of electricity (Fig. 6) are plotted with a gradual increment in each step of 0.127 cents/kWh (BDT: 0.1 taka/kWh).

Considering 54% increased plant O&M costs, 40% increased fuel costs, and keeping the same PCFs compared with the four low case cost studies of 1–4, the LUEC values at the four case studies of 5–8 stand to 6.37, 6.16, 5.94, 5.75 cents/kWh respectively at which NPV=0. And then, above those LUEC points, NPV becomes positive and below those LUEC points, NPV becomes negative. Even though for considering such high O&M costs and fuel costs over the 60-year lifetime of the plant, the variation of IRR over the LUECs is found insensitive which means O&M costs and fuel costs do

not much affect generation costs if the discount rate, investment costs, and construction time remain fixed. With the increase of O&M costs and fuel costs, only a slight variation of the unit selling price of electricity (\cong 1cent) is found in comparison with the low O&M costs and fuel costs scenarios. And no major variation is found in the NPVs amongst all the case studies. From these findings, it can be said that levelized generation costs of an NPP do not depend much on O&M costs and fuel costs as these are contributing small portions of the lifecycle costs of the plant.

5.3 Case study-9: Worst scenario

Figures 7 and 8 show the selling price of electricity considering high O&M costs, fuel costs, and very low PCF of 50%. Under this extreme situation, a high LUEC value of 8.25 is found at which NPV=0 with the threshold IRR value of 14.1%. Considering such an extremely low value of PCF, it impacts on the LUEC value but it does not impact on the IRR. This 50% low PCF can be thought of due to a shortage of electricity transmission network, grid instability, failure of major electrical equipment (generator, transformer, etc.), and inefficient fuel management during the operation lifecycle of the plant for an inexperienced and low technologically ad-

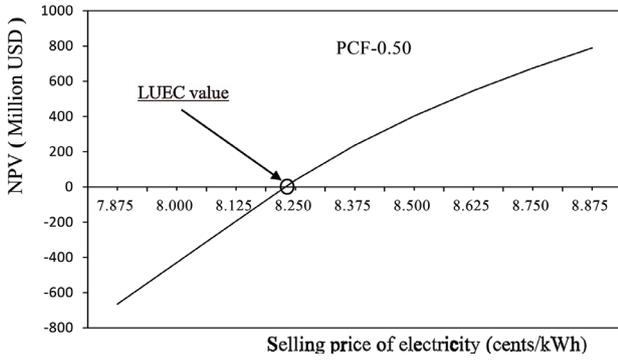


Figure 7. Variation of NPV with selling price of electricity (cents/kWh) considering high plant O&M costs-14.5\$/MWh and fuel costs-11.2\$/MWh, discount rate-10% and PCF-50%.

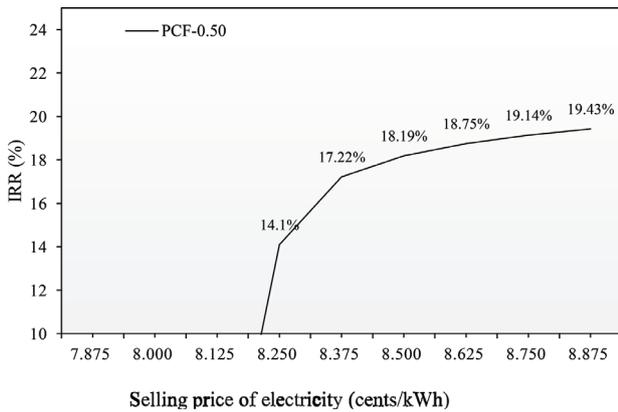


Figure 8. Variation of IRR with selling price of electricity (cents/kWh) considering high plant O&M costs-14.5\$/MWh and fuel costs-11.2\$/MWh, discount rate-10% and PCF-50%.

vanced countries like Bangladesh. In summary, the LUEC values are found in the range of 4.37–8.25 cents/kWh at nine postulated case studies. The case study-9 anticipates the worst possible scenario. However, the estimation of LUEC under the worst case scenario shows good agreement with the LUEC estimations of Sied et al. (2015) and Rahman (2016). Furthermore, LUEC predicted by Bazlul and Iftekher (2017) shows disagreement with our estimations.

5.4 Comparison of LUECs with other power generating sources

Figure 9 shows the comparison of LUEC values of the Rooppur NPP project with other available power generating sources in Bangladesh. According to the BPD-B's 2018–2019 annual report, LUEC values for its own plants varied from 3.13 to 54 cents/kWh. The LUEC value of 3.13 cents/kWh is the cheapest for the indigenous gas based power plant. However, future electricity costs from gas source will not be cheap as indigenous gas supply has been decreasing gradually and the shortfall will be filled in by imported LNG. Coal based power plant shows little bit high cost due to mixed mode coal

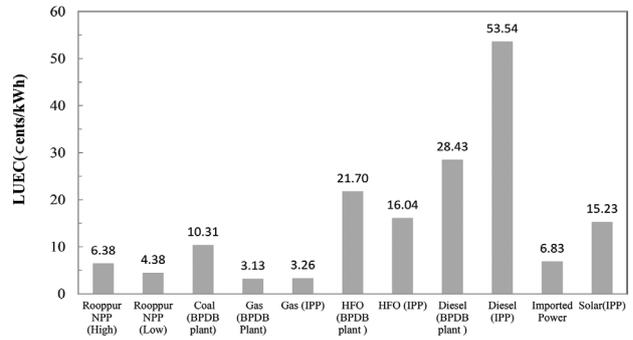


Figure 9. Comparison of LUEC with other power generating sources in Bangladesh (BPDB 2018–2019).

supply from home and abroad. Heavy fuel oil (HFO) as well as diesel fuels which are used in power generation in both government and independent power producers (IPPs) show a high rate of electricity generation because of being costly imported oil (BPDB 2018–2019). Hence power generation from the Rooppur NPP project shows very much cost competitive with gas, coal, and imported electricity from India except oil and solar based power generating sources.

Figure 10 compares the LUECs of Bangladesh, Belarusian, and Hungarian NPP projects with the other two baseload power sources such as gas and coal. The LUEC calculated by Sied et al. (2015) using the INPRO model shows slightly high for the Rooppur NPP project compared with coal and gas fired power plants. In our analysis, the FINPLAN model predicts a lower estimation of LUEC for an NPP. The reasons for variation in LUECs are due to considering overnight construction costs of \$5000/kWe instead of lifecycle costs. In the case of the Belarusian NPP project at Ostrovetz, IAEA calculation using the INPRO model shows slightly high electricity costs for the coal and gas fired power plants in comparison with nuclear (IAEA/INPRO 2013). Costs of electricity both nuclear and coal are found almost the same trend during the economic evaluation of the Hungarian Paks II NPP project. Three countries are constructing the same reactor model, electric output, similar financial terms and conditions, and same vendor country i.e. Russia. Among the three NPP

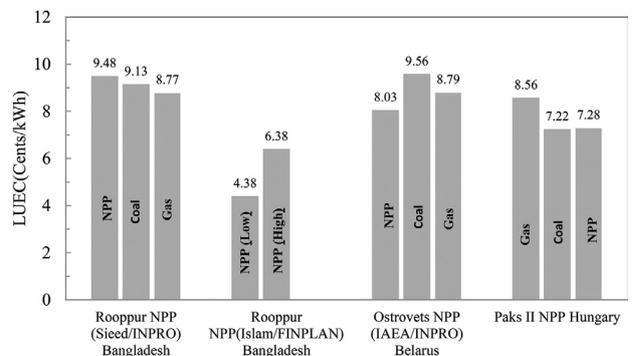


Figure 10. Comparison of LUEC of the three VVER-1200 Gen III+ NPP projects with two baseload power sources (IAEA/INPRO 2013, Paks II 2015).

projects, the costs of the Rooppur NPP project both low and high end cases show the most competitive, attractive, and risk acceptable compared with coal and gas fired power plants.

Figure 11 shows the LUECs of global NPPs. The highest lifecycle cost appears in the UK. The US and some European countries are found in similar trends in nuclear power generating costs while South Korea and China are found to be the lowest generation costs. Bangladesh stands to China and South Korea, and about half the global average unit generation costs (9.59 cents/kWh).

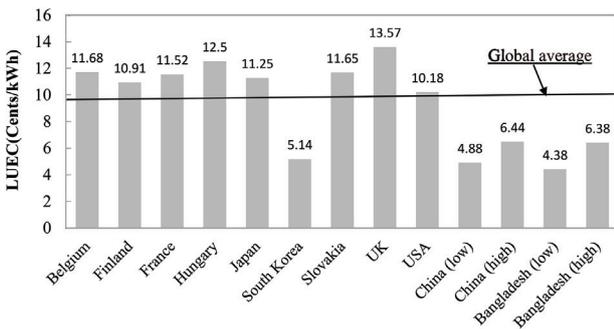


Figure 11. Comparison of LUEC values with global nuclear power generating countries (discount rate of 10% and PCF of 85% (OECD/NEA 2015)).

5.5 Payback period

Figure 12 shows the project cumulative cash inflows that is loan drawn during the construction period (2017/18–2022/23) and the revenue earning from electricity sales at eight postulated case studies excluding the worst case scenario (Case-9). The breakeven point at four case studies of 1–4 is found to be in 2028 and the rest four case studies of 5–8 are found to be in 2029. The project will have cash inflows from the electricity sales in the same amount of its total investments within 7–8 years after the start of commercial operation of the two units in 2023 and 2024. Sensitivity analysis indicates that the return of investment of the project is not overly sensitive to the PCF over the operational lifetime of the plant. For a higher LUEC, quicker PBP is expected for a discount rate of 10% and a plant lifetime of 60-year.

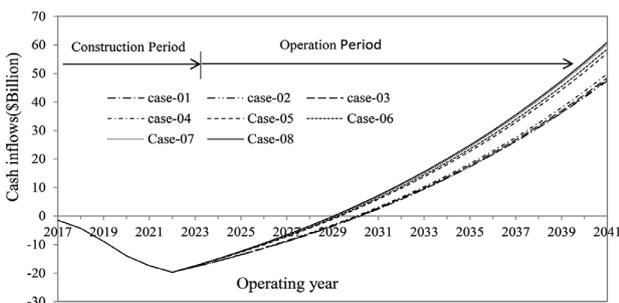


Figure 12. Cumulative cash inflows profile of the Rooppur NPP project (Billion USD).

5.6 Cumulative loss/profit

Retained earnings (cumulative loss/profit) over the whole 60-year operation lifecycle of the plant at eight different postulated scenarios is accumulated to be 15.72 to 192.96 billion USD respectively. The revenue generated at eight cases during the operational period is anticipated to be sufficient to cover the annual cost of O&M including the funding of waste management, decommissioning, and the payment of taxes. This can be seen in Fig. 13 that the profit is adequate to enable the State to cover the cost associated with repaying the financial credit agreement and to receive investment.

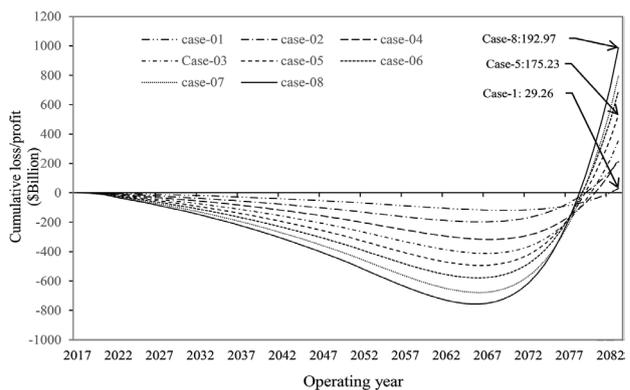


Figure 13. Illustrative retained earnings at eight different case studies of the Rooppur NPP project.

6. Conclusion

Evaluation of financing and economic risks associated with the construction of a new build NPP is an important prerequisite for a successful nuclear power program. Such investment risk should be acceptable in comparison to other available power projects. The article calculates the economic and financial indicators e.g. LUEC, NPV, IRR, and PBP to show how potential and economic robustness of the Rooppur NPP project is. The LUECs of the Rooppur NPP project are found in the range of 43.8 to 63.8\$/MWh at the eight different postulated scenarios from low to high O&M costs (7.82–14.5\$/MWh and low to high fuel costs (4.5–11.2\$/MWh) with the four PCFs of 75, 80, 85 and 90%. Even though considering the 45% high O&M costs and 40% high fuel costs with regard to the low case scenarios of 1–4, the LUEC becomes at 63.8 \$/MWh at a PCF of 75%. In these high O&M costs and fuel costs scenarios, at which NPV=0, the threshold IRR value is found in the range of 16.63 to 17.78% against the discount rate of 10%, which shows an attractive rate of return. With the increase in the selling price of electricity, NPV becomes positive and the IRR reaches up to 20% in all case studies. The PBP for accumulating the capital investments from electricity sales after the start of commercial operation in 2023 and 2024, will be the at least in 2029. This plant may bring a cumulative profit of around 15.72 to 192.96 billion USD respectively at the eight different scenarios over the

60-year uninterruptable reactor operation. Apart from the eight different case studies, the LUEC is found as 82.5\$/MWh when the worst case scenario is anticipated.

In this analysis, the LUECs from the Rooppur NPPs are found to provide a reasonable and attractive rate of return with regard to the coal, oil, and renewables. LUECs from the Rooppur NPPs show slightly costlier than the gas based power plants. However, this advantageous situation is yet to remain last long as gas based power plants are going to be replaced by the imported expensive LNG. The financial and economic analyses of the Rooppur NPP project in Bangladesh are found to be in a favorable condition than those of the Belarusian and Hungarian NPPs projects. From the global perspectives, LUECs for nuclear power in Bangladesh also stand to a suitable situation. These assessments limit a particular discount rate of 10%, a fixed investment cost, a fixed construction time, uncertainty in taking the actual O&M costs and fuel costs, and considering up to the 60-year reactor design lifetime. Life extension of the two reactors is not considered during economic evaluations of the plants. Since the country has no NPP operating experiences, this may bring uncertainty in maintaining the plant with high PCFs of above 75% as the average PCF of the fossil fuel power plants is 50%. To keep maintaining the LUECs from nuclear power more competitive with gas, coal, and renewables, the operating organization has to operate and maintain the NPPs locally with skilled workforces. This study suggests for developing trained manpower as well as ensuring the stable electrical grid system, and market demand for maintaining a higher PCF.

Furthermore, the macro-economic impact for introduction to this large scale modern Gen III+ baseload NPP is huge and it creates a good number of employment opportunities, manufacturing capabilities, infrastructure, power, and environmental developments. Since there are no publicly available financial and economic analysis of the Rooppur NPP project, it is imperative to have a detailed techno-economic and financial report using real-life data to perceive actual risk. Although there exist some risks in investments due to unforeseen reasons, operating the Rooppur NPPs in a safe and secure manner still appears to be instrumental for sustainable development with clean energy sources in Bangladesh.

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List of acronyms

BPDB	Bangladesh Power Development Board
BDT	Bangladesh Taka
FINPLAN	Financial Analysis of Electric Sector Expansion Plans
HFO	Heavy Fuel Oil
IRR	Internal Rate of Return (%)
IGA	Intergovernmental Agreement
IAEA	International Atomic Energy Agency
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
IPP	Independent Power Producers
kWh	kilowatt hour-Energy unit
LUEC	Levelized Unit Electricity Cost (\$/kWh)
LCOE	Levelized Cost of Electricity (\$/kWh)
LNG	Liquefied Natural Gas
MWe	Megawatt Electric-Power Unit
NPV	Net Present Value (\$ million)
NPP	Nuclear Power Plant
NEA	Nuclear Energy Agency
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
PSMP	Power System Master Plan
PBP	Payback Period (yr)
PCF	Plant Capacity Factor (%)
US	United States
USD	United States Dollar (\$)
USDOE	United States Department of Energy
VVER	Water-Water Energetic Reactor

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