Comparative Analysis of Renewable Power Generation Technologies in Bangladesh: Technical, Economic and Environmental Aspects

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Renewable energy plays an important role in strengthening the global energy security as fossil fuel resources are depleting day by day. Approximately 25% of total primary energy supply of Bangladesh comes from renewable sources, especially from biomass, solar, hydro, and wind. Biomass still is the major renewable fuel source. However, the use of biomass is still primitive, in the form of cooking fuel in traditional cookstoves. These resources have greater potential in our energy mix then their current contribution. Detailed research on their availability and potential technologies in the conversion of fuels is necessary. Till now the research on this field is limited and no such major work can be identified which studied the overall impact of the major renewable resources on our energy sector. The main objective of this study is to understand the potential of renewable resources and analyze the impact of utilizing these resources in the context of Bangladesh. Several models had been developed to study utilization of these resources (e.g., biomass, solar, hydro, and wind) in the form of electricity using RETScreen 4 software. With these models, this study critically assessed the financial viability, GHG emission reduction, sensitivity and risk of each project. Different input parameters, for example, capacity, multiple fuel options, and possible technology for power generation are used to compare these models to get the most feasible options. From this study, the 20 MW hydro project at Sangu and 5 kW off-grid solar project were found economically and environmentally promising. 5 kW solar home project can save 2.3 ton of CO_2e GHG emission and annual savings with an annual revenue of $1435. Likewise, 20 MW hydro project in Sangu river can reduce 46,967 ton of CO_2e GHG emission and annual savings or income can be approximately $4.9 million. However, biomass, large scale solar projects and wind power plants are not economically feasible and hence, need financial support. To make the best use of these resources, some modifications in the national energy policy are essential to deploy these projects which were also included in this study. This research can help the policy planners and decision-makers to understand the prospect of each potential resource of Bangladesh along with its future impact before implementation.

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LIST OF SYMBOLS AND ABBREVIATIONS

B-C	Benefit-Cost ratio
CAPEX	Capital Expenditure
FCI	Capital Investment
ERL	Eastern Refinery Limited
EFOM-ENV	Energy Flow and Optimization Model–Environment
ENPEP-BALANCE	Energy and Power Evaluation Program
GAMS	General Algebraic Modelling System
GIIP	Gas in Place
GWP	Global Warming Potential
GHG	Greenhouse Gas
HP	Hydropower
IRR	Internal Rate of Return
kWh	kilowatt-hour
LEAP	Long-range Energy Alternatives Planning System
LEDS	Low Emission Development Strategies
MESAP	Modular Energy System Analysis and Planning Environment
Mono-Si	monocrystalline silicon
NGL	Condensate and Natural Gas Liquids
NPV	Net Present Value
PlaNet	Planning Network
PDP	power development plan
1P	recoverable Proved reserve
2P	Proved + Probable reserve
3P	Proved+ Probable+ Possible
RETs	Renewable-energy and Energy-efficient Technologies
ROI	Return on Investment
SSHP	Small Scale Hydropower Plant
SHS	Solar Home System
SDG	Sustainable Development Goals
TPES	total primary energy supply
U/G	Underground
UNFCC	United Nations Framework Convention on Climate Change

1. INTRODUCTION

1.1 Background

Bangladesh is a developing country having a GDP of 8.13% in 2018-2019. It is having almost stable economic growth of more than 6% during the last 8 years [1-2]. A large portion of the population of Bangladesh is involved in the industrial and business sector as their major source of income. Rapid urbanization with stable economic growth plays a key role in this development. It also accelerates energy demand in recent years. This rising energy demand helps ensure overall economic growth, poverty elimination, sustainable development and maintain energy security.

At present, 25% of the Bangladesh's total primary energy supply comes from renewable sources, mostly in the form biomass with insignificant contributions from solar, wind and hydro [3]. However, in the power sector, contribution of renewable resources is far less, only 2.3% according to BPDB [4]. Considering the off-grid power generation by solar home, wind, and biomass/biogas to electricity around 3% of total generation is renewable [5]. The Government of Bangladesh has a plan to generate 20% electricity from renewable resources by 2020 [6]. The low penetration of renewable resources in energy sector is due to availability of cheaper non-renewable energy sources as well as lack of policy framework at the national level [7].

In Bangladesh, energy is mainly consumed as electricity, transportation fuel, or cooking fuel. Among these, electricity is a mostly used form of energy. Annual capacity of electricity generation was 18961 MW and energy consumption 70533 GWh in 2019, more than the projection made in PSMP 2016. Annual power demand was forecasted as 12143 MW for 2019 in PSMP 2016 [4]. This increasing power demand is achieved from natural gas, crude oil or refined products, coal, renewable resources, imported LNG, LPG, and imported electricity. To secure energy demand, the government is expanding the capacity of each sector rather than importing direct electricity. Government of Bangladesh also adopted several Sustainable Development Goals (SDG). It includes ensuring access to affordable, modern energy for all by 2025 and increase the share of renewable energy upto 10% of total energy consumption by 2030. Renewable energy was utilized 3.25% in 2019 according to SDG Tracker [8]. Only 2.73% of the total electricity is generated from renewable resources as of 2018 [4].

Currently, Bangladesh has launched many projects from renewable resources—biomass, solar, hydro, wind—with the collaboration of several organizations, such as SREDA, IDCOL, World Bank, and so on. For example, 50 MW solar park mega project has been completed in 2020 in Mymensingh which is financed by IPP [9]. Two self-financed wind projects with total capacity of 2 MW have been completed in Kutubdia, Cox's Bazar by BPDB [10]. Moreover, One off-grid biomass to electricity project with capacity of 400 kW is running from 2015 which was financed and installed by IDCOL [11]. Corresponding electricity generation cost from solar is \$0.18/kWh, and from wind \$0.96/kWh.

Adoption of renewable energy technologies holds the key to the sustainable economic development resulting low impact on environment. A recent study suggests that Bangladesh has a maximum renewable energy potential up to 3700 MW [12]. To realize this potential, reliable information, planning, and feasibility study are necessary. This current study focuses on the technical, environmental, and economic assessment of power generation from renewable energy options, namely solar, wind, hydro and biomass.

1.2 Objectives

The overall objective of this research was to perform a comparative analysis of the electricity generation potential from different renewable resources in the context of Bangladesh and present the result in measurable variables. This research also explored the scope of each renewable resource considering the current situation of Bangladesh and launch an energy modelling technique to demonstrate the scope, potential, and impact using this software. One of the main objectives of this study was to determine the technical feasibility, economic viability, and environmental impact of electricity generation from these sources. Another objective was to assess the existing renewable energy policies and suggest necessary modifications or suggestions, if required, based on the outcomes of this analysis to make the renewable power generation competitive in the context of the current energy market. Ultimately, the outcome of this research is to set ranked portfolios of renewable energy to electricity in terms of reliability, cost, and environmental impacts.

1.3 Methodology

An extensive study was performed on the current energy situation and future projection of potential resources of Bangladesh to understand the prospect and scope of energy modeling in order to perform a feasibility analysis of the current renewable energy policy. Energy modeling is a supporting tool to understand the project outcomes prior to implementation and decision making. Through this energy modeling impacts and outcomes of the current renewable policy was analyzed using RETScreen software version 4. RETScreen is an energy modeling software that is widely used across the world to analyze project feasibility, performance, impacts, or risks of renewable or clean energy projects [13-15]. With this software several energy models were designed for each renewable resource, for example, biomass, solar, wind, and hydro with relevant inputs considering the current context of Bangladesh. This research also made the best effort to make this study the most reliable concurrently comprehensive.

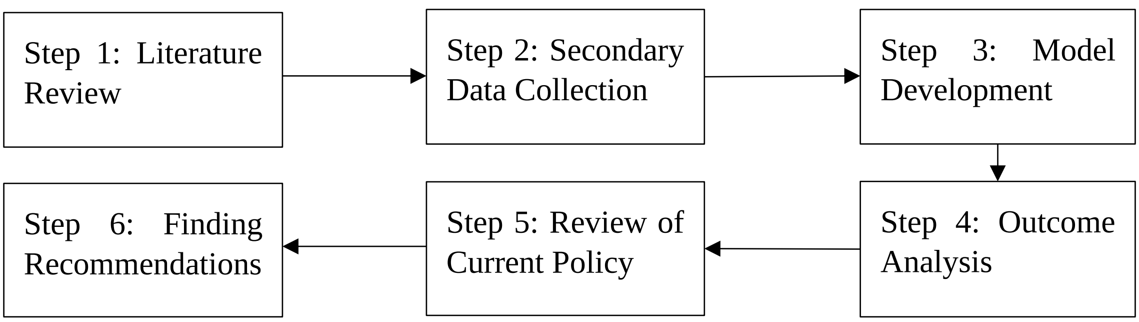


Figure 1-1: Flow diagram of methodology followed in this research.

From the outputs of these models, technical features, economic feasibility, and environmental impacts were analysed and critically assessed. Any risk in terms of technical, economic, and environmental perspectives involved in these projects was also identified and included in this study. Eventually, this research also incorporated implications, scopes to improve, and highlighted the associated risk of each model.

1.4 Scope of the Study

This research would give an insight about using an energy modeling approach to find the most feasible option to evaluate the electricity generation potential of renewable resources. It included all four major renewable sources—biomass, solar, wind, and hydro—in this study. It also explored different technology, scale, and location to make this evaluation mostly relevant and comparable to the current context. This kind of research has not been done yet concerning the current situation of Bangladesh that includes project feasibility of all potential renewable resources. This technique is quite easy, convenient, and straightforward as it requires less data as input and provides important parameters that make it user friendly. It would also act as a platform to launch this kind of pre-feasibility and feasibility analysis for future projects before launching them. Key features of the RETScreen models are summarized in Table 1-1.

Table 1-1: Key features of the models that is covered in the study.

Model Name	Power from Biomass Model	Solar PV Model	Wind Power Model	Hydro Model
Project Type	Gas turbine single cycle, Steam turbine, Gas turbine Combined cycle- Single fuel/Dual fuel (Biomass-Diesel: 50%-50%/75%-25%)	Industrial-scale and small scale (SHS) Photovoltaic Project	Small scale and large-scale Wind projects	Small Scale Hydropower Plant (SSHP) - Run of river
Location	Dinajpur	Dinajpur	Chittagong, Mongla, Cox’s Bazar	Matamuhuri, Sangu River
Power Capacity, MW	1, 2, 5	250, 5 kW	1, 5, 50	1, 20
No of cases to be studied	37	2	3	2

This comparative analysis can help planners and decision-makers to immediately identify, assess, and optimize the technical, financial, environmental features of potential clean energy projects. Additionally, multiple criteria assessments including sensitivity and risk parameters for each model make this analysis more effective than other techniques. Besides, comparative analysis can be easily accomplished between multiple potential projects and based on that most favourable one can be chosen for implementation. A similar method can also be used to review the energy policy before implementation and make recommendations to update the policy. Consequently, based on the model outcomes, some implications were also made on current renewable energy policy. Moreover, the scope of this study covers a knowledge-sharing platform in a standard manner throughout the process.

1.5 Thesis Organization

Chapter 1 includes background, objectives, and scopes of this study. Overall thesis outline was explained briefly in this section.

Chapter 2 contains literature review of this research. Mainly current energy situation of Bangladesh, power demand and future projection, current reserve, and power generation contribution from major sources—both fossil fuel and renewable sources—are also briefly discussed. Besides, overview of prospect, scope, and classification of different energy modeling were also included.

Chapter 3 basically delineates thorough methodology of this study consisting of steps involved in designing each energy model in RETScreen, description of model parameters and analogy of these inputs.

Chapter 4 of this study covers result obtained from these energy models and comprehensive discussion and critical analysis of the outcomes of each model. It includes technical, economic, environmental and sensitivity analysis of each model in the context of Bangladesh. Outcome, associated risk, possible implication and scopes are also discussed.

Chapter 5 consists of summary of findings, implications, overall limitations, and concluding remarks along with scope of future study.

2. LITERATURE REVIEW

2.1 Introduction

Bangladesh has a rapidly growing economy. To make a good economic balance, it needs to change its strategy of existing dependency on domestic natural gas to imported energies to meet the increasing energy demand. Planning and efficient utilization of these resources are ineluctable. A thorough study has been performed on the current situation on primary energy sources i.e., natural gas, coal, oil, LNG, and renewable resources i.e. solar, hydro, biomass, and wind. In the future, the efficient use of energy resources along with prescient energy policies and systems would be essential. Policy and system up-gradation include tactical planning of multiple energy resources and more efficient use of these resources by amending the current policy.

Energy modeling can give macro planning and measure outcomes in terms of economic and environmental perspective. Energy-modeling is a computer-based simulation of a far-sighted energy plan that focuses on energy savings, energy conversion performance, efficiency, loss factors, demand and supply, capacity factor, greenhouse emission, risk factors and long-term impact of different sources of energy and so on. It is also used to measure the breakeven point or equity payback of clean energy projects, such as solar projects, wind turbines, hydropower plants, biomass power plants, hybrid energy systems, and energy-efficient instruments. Before starting energy modeling, it is important to study relevant energy modeling techniques, the existing energy situation of Bangladesh, the supply and demand of energy sources, national energy policy, and renewable energy policy.

However, decision making of a project can be done based on the outcome of energy modeling of that project or energy source. Existing energy policy can be challenged with the findings of this study. The recommendation would be another outcome of the implication of energy modeling. It can be a guideline for future energy planning and policymaking. This study focused on renewable energy modeling to understand the resource potential and future impact of these technologies in terms of technical, economic, and environmental for the next 20 to 30 years.

2.2 Energy situation of Bangladesh

Bangladesh’s energy need has been increasing rapidly and will be growing this way in the future. Natural gas has been the key source of energy for more than half of the total demand for power generation, but the reserve of natural gas will deplete soon. Figure 2-1 illustrates the historical trend of primary energy supply in Bangladesh. From this trend, the contribution of natural gas in total primary energy supply shows an increasing trend until 2010. From 2011, this contribution of natural gas came to saturation as domestic production of natural gas is almost constant. Increasing energy demand is mainly covered by petroleum products [1].

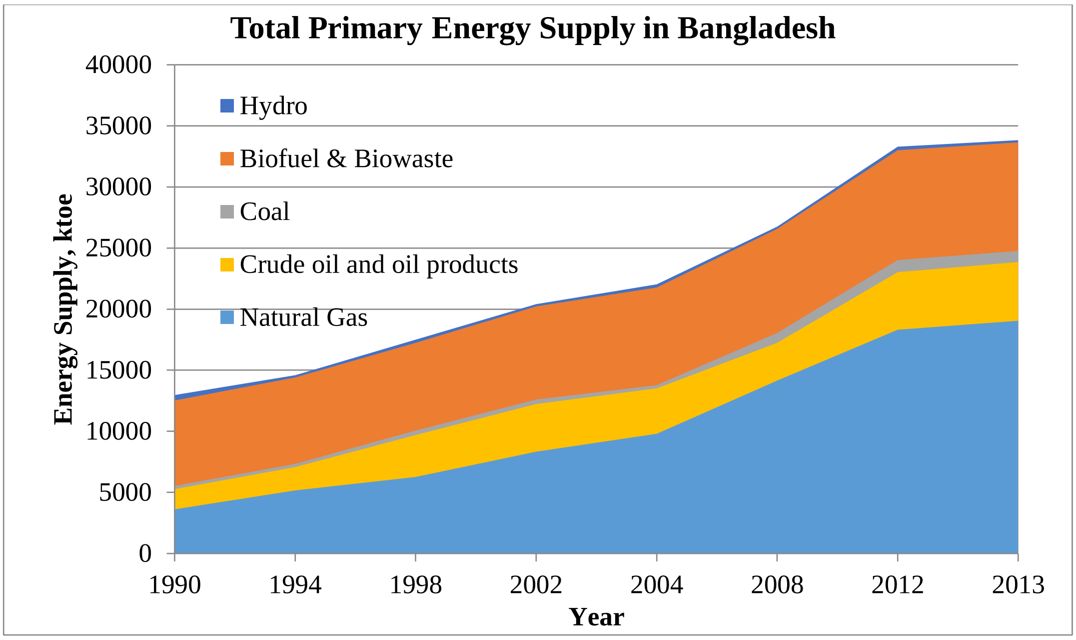


Figure 2-1: Historical trend of primary energy supply in Bangladesh [2]

The projection of the primary energy supply is demonstrated in Figure 2-2 and Figure 2-3. The approximate growth rate of 4.8% in annual primary energy demand is projected till 2041. A notable amount of growth is forecasted from coal and renewable resources for power generation. Moreover, oil demand slightly exceeds the projection due to increasing demand in the transport sector.

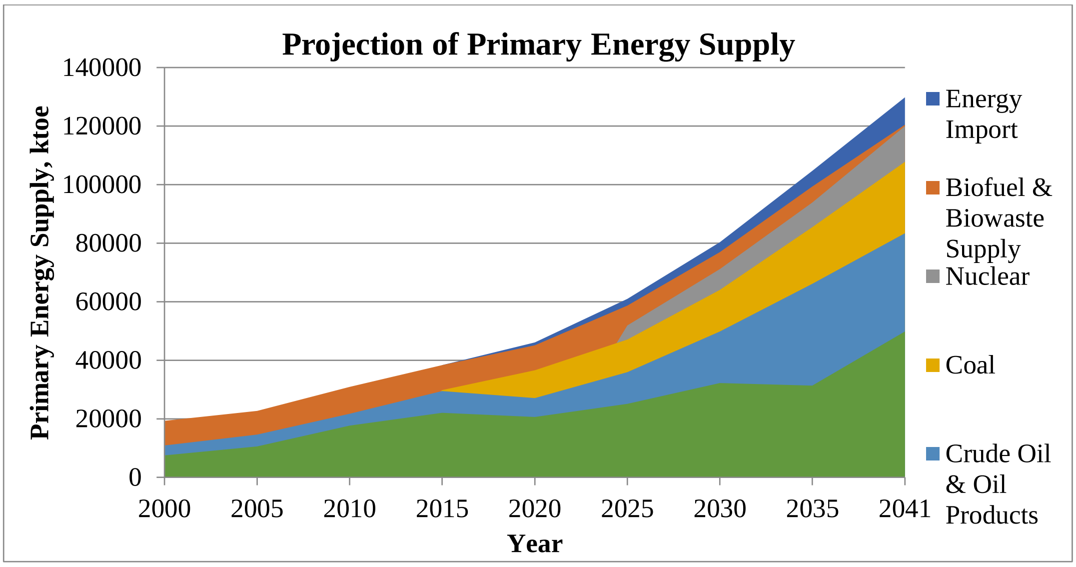


Figure 2-2: Projection of Primary Energy Supply [1]

Based on the projection of total final energy demand, the total primary energy supply (TPES) in Bangladesh is projected up to 2041. Energy demand as electricity, gas, oil products, is determined for each sector. In the industrial sector, the source of electricity is planned to almost be constant in several coming years. Natural gas, coal, and oil will be the main contributor. In the long run, captive power generation from natural gas is planned to be replaced by power from the grid. In the transport sector, one-third of sharing will come from natural gas and two-third from oil. Fifty percentage sharing of electricity and natural gas will be maintained in the public and commercial sectors.

Due to rapid economic growth in Bangladesh, a power development plan has been designed to accelerate power generation facilities to meet the increasing power demand. Meanwhile, Table 2-1shows yearly power demand during the summer for the 2015-2040 period.

Table 2-1: Maximum power demand from 2015 to 2041[1].

Year	2015	2020	2025	2030	2035	2040
Power Demand,	8921	12949	19191	27434	36634	49034

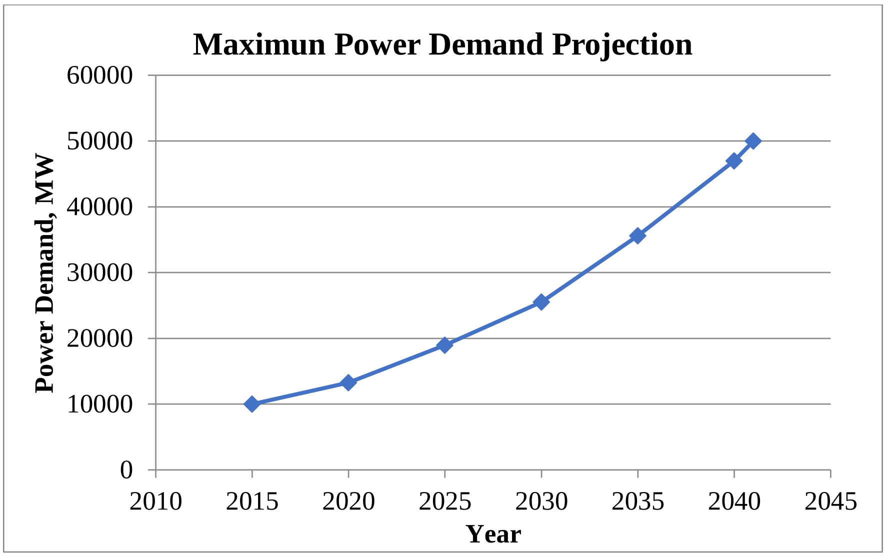


Figure 2-3: Projection of maximum power demand [1].

The power demand forecast is a complicated factor as it is nearly impossible to exactly predict the future demand for the next several years for with most accuracy. A future power development plan (PDP) needs to be prepared considering all elements including demand variables, sensitivity analysis of these variables to a certain range, power generation facilities, economic, environmental, and energy security values. This study only considered approximate estimation of future power demand macro-economic growth and formulated optimal PDP presuming peak demand projection.

2.2.1 Natural Gas

Natural gas has been the most significant primary energy source to supply the increasing power demand in Bangladesh. This increasing demand is met by domestic production of natural gas, but it has come to saturation after 2010. It will run out very soon and its economic value should be realized more efficiently.

Figure 2-4 shows the historical trend of natural gas consumption by major sectors. This figure also indicates the domestic production of natural gas each year until 2013. In Bangladesh, the demand for natural gas was almost 100% fulfilled by domestic production of natural gas till 2017, and thus almost entire production was consumed. Gas production in Bangladesh rose to 2754 mmscfd in 2017 [3]. Power generation is around 50% of the total consumption of natural gas in recent years. In the meantime, the consumption of the industrial and the transport sector has been continuously increasing, and non-energy consumption (as a raw material of chemical fertilizer) has been reducing [1]. Bangladesh has already started importing LNG to increase natural gas supply and support increased demand for electricity.

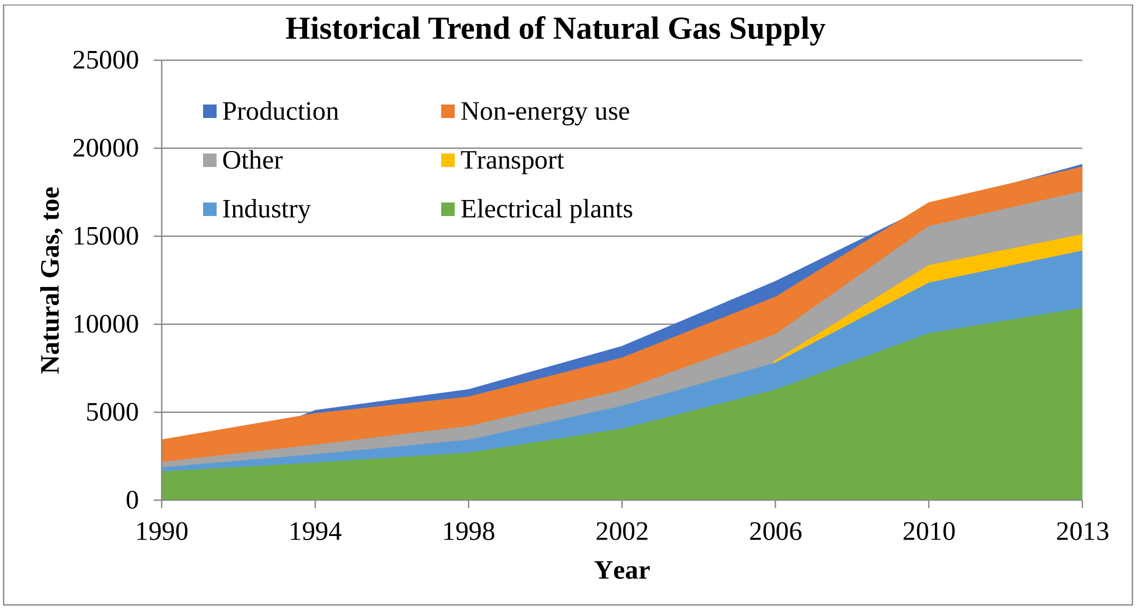


Figure 2-4: Historical trend of supply of Natural Gas [2].

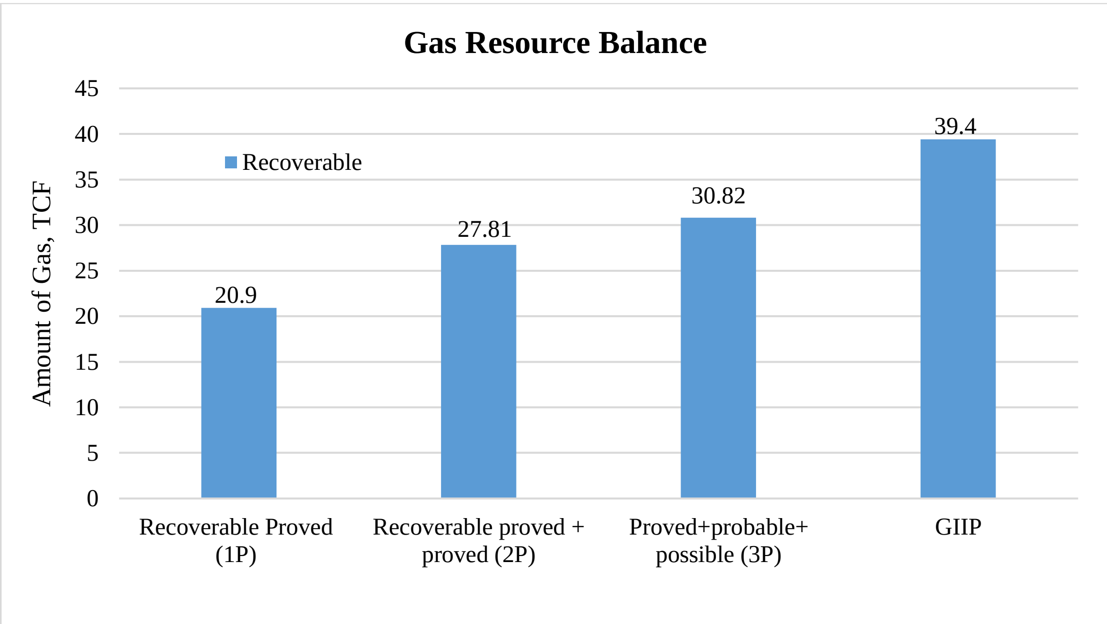


Figure 2-5: Gas Resource Balance [4].

According to the Petrobangla report, the total estimated Gas in Place (GIIP) in Bangladesh is 39.8 TCF and the recoverable Proved reserve (1P) of natural gas in Bangladesh is 20.9 TCF. About 16.44 TCF has been produced and consumed by

December 2018. The remaining gas reserve will be 11.47 TCF from 27 fields. Proved + Probable (2P) reserve is 27.81 TCF and Proved+ Probable+ Possible (3P) is 30.82 TCF [4].

Bangladesh has scopes to improve the efficiency of domestic natural gas recovery by introducing advanced technology and mechanism. This improvement can save a big amount of wastage of natural gas, around 52 BCF per year if the current average recovery efficiency of 38% could be increased to 45%. However, the rigorous exploration program of BAPEX would also be worthwhile to find new gas fields to sustain the current production level and to meet increasing demand. Additionally, newly installed and planned LNG import terminals along with regasification units would also be promising to ensure energy security.

2.2.2 LNG

Gas demand in Bangladesh is significantly increasing as the domestic natural gas reserve is depleting. To make a good balance on demand and supply, the LNG import project is launched by Petrobangla in 2016. The first FSRU to import LNG was launched in 2018 with a capacity of 500 mmscfd corresponding 17% of gas demand. 2nd FSRU was also started commercially in 2019. its pre-commissioning and commissioning acceptance test and started to serve gas in the national grid. In total 1000 mmscfd gas is provided from two FSRU jointly per day [5]. This percentage is forecasted to increase to 40% in 2023, 50% in 2028, and 70% in 2041 [1]. Bangladesh has planned to launch around 3000 MW LNG based electricity generation projects by 2023 [6].

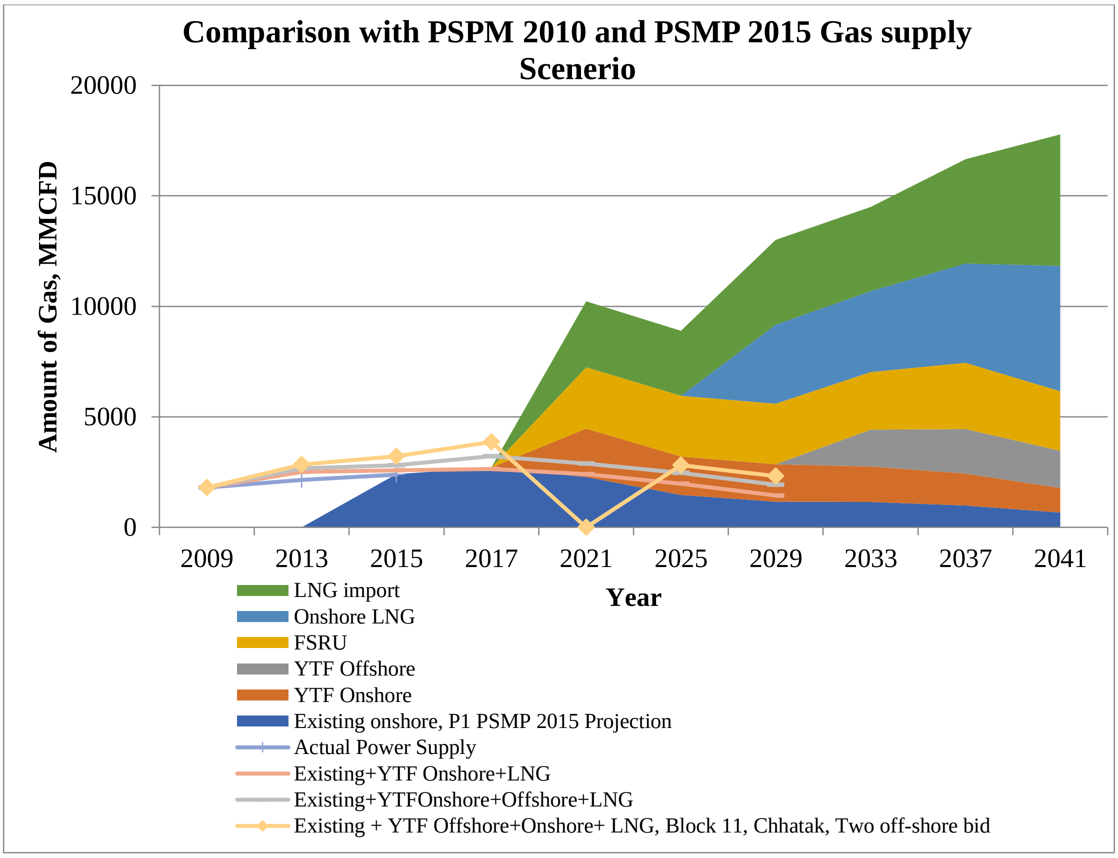


Figure 2-6: Gas Supply Forecast 2016~2041 [1].

LNG projects also need investment in land acquisition and gas handling capacity improvement with the increase of capacity and demand. Land-based LNG terminal might require long-term planning whereas FSRU takes less than three years. But it is environmentally more hazardous than land-based terminals as it needs a more frequent ship to ship LNG transfer. Additionally, with the increase of power demand and supply, pipeline infrastructure for transmission to the existing facility also needs to be planned well in advance.

2.2.3 Coal

The historical trend of supply and demand for coal in Bangladesh is discussed in this section. The resource of natural gas is limited and almost saturated. Coal is an alternative option to replace this need. Coal is the cheapest primary energy and that is why coal-fired power stations may flourish in Bangladesh. Moreover, high-quality coal is available in Bangladesh which is a good source of electricity. Additionally, to support the increasing power demand, the import of coal supply is planned to increase up to 60 million tons by 2041.

Coal is usually categorized as bituminous coal in Bangladesh, due to its lower ash content and low sulfur content which is conducive for the environment. Table 2-2 shows the estimated minable coal reserve depending on open-cast and underground mining methods. The total reserve of measured and probable coal is 3.3 billion tons. 430 million tons is anticipated as the quantity of actual minable coal based on present mining technology. Moreover, the measured coal reserve that can be mined is estimated as 1168 million tons except in Jamalagonj as its coal seams are situated relatively deeper below the ground [1].

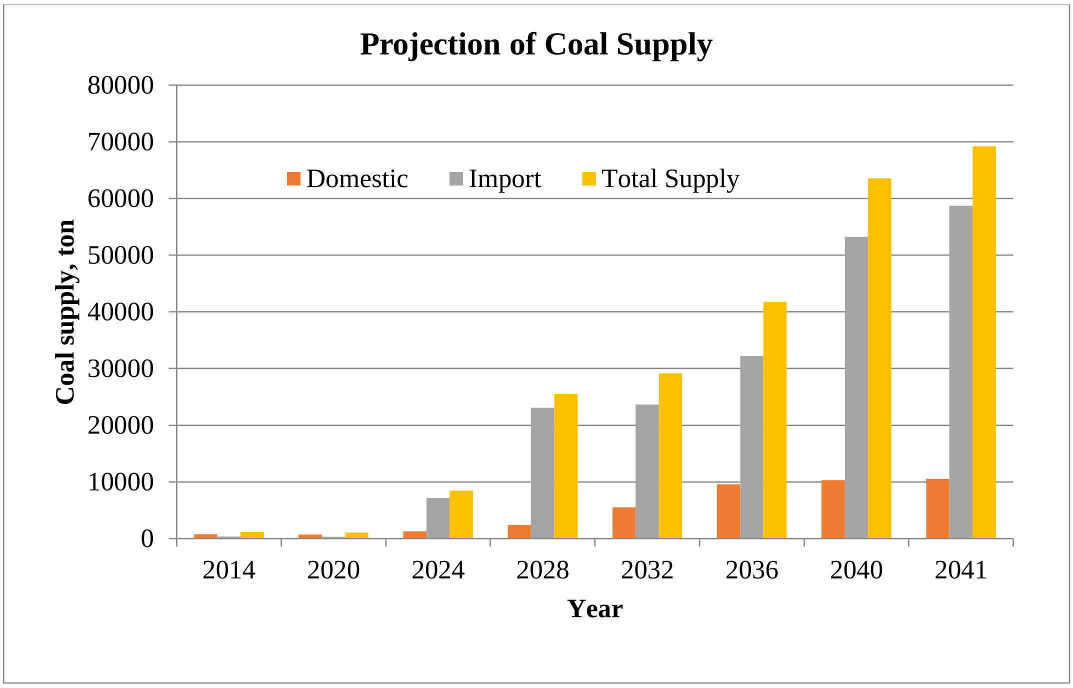


Figure 2-7: Projection of Coal supply [1]

Coal had contributed around 1.74% of total power generation in 2019. Currently, Bangladesh has two coal power generation units with a total capacity of 1845 MW in

Barapukuria and Payra. Besides that, Bangladesh had planned to install an additional 5491 MW coal-based capacity by 2023 [6].

Handling is the most important for coal import whereas coal center barge transport and offshore unloader are also a part of handling. Coal Center will play a major role in the future as a stable coal supply is the most challenging issue for a power station. However, the coal-based power plants in southern Asia increased rapidly, quality, supply, and price of imported coal might become very unsecured in the upcoming years.

Table 2-2: Minable Coal Reserve depending on Mining Method [1]

Sl. No.	Location of Coal Field	Depth, m	No. of Coal Seams	Av. Thickness of composite coal seams,	Measured reserves, 10^6 tons	Maximum Recovery with Underground (U/G) mining	Minable Coal Reserve, 10^6 tons
1	Barapukuria, Dinajpur	118-506	6	51	303	U/G (15%)	45.5
2	Phulbari, Dinajpur	150-240	3	15-70	572	U/G (60%)	343.2
3	Khalashpur, Rangpur	257-483	8	42.3	143	U/G (15%)	21.5
4	Dighipara, Dinajpur	328-407	5	62	150	U/G (15%)	22.5
5	Jamalgonj, Bogra	640-1158	7	64	1053	U/G (10%)	105.3
6	Kuchma, Bogra	2380-2876	5	51.8			
7	Total Coal Reserve, 10^6 tons						438
8	Maximum recovered coal, 10^6 tons						10.16

2.2.4 Oil

Currently Bangladesh has an annual demand for oil around 5.5 million tons [7]. Due to increasing demand in the industrial and transport sector, oil demand is forecasted to grow six times from 2014 to 2041 (average growth rate 7% p.a.). Bangladesh has a plan to extend or develop oil refineries. However, oil demand will rise as projected, an increase of oil import will also be inevitable to meet the extended demand. Figure 2-8 shows the historical trend of demand of petroleum products and consumption is broken down by major sectors [1].

In Bangladesh, domestic production of petroleum is far less than the demand, and the demand is met mostly by imports. Power generation from petroleum products has been increasing rapidly since 2011, for which dependence on imported petroleum has been increased. Almost 75% of the oil demand was met by diesel oil because of its extensive use in various sectors from transportation to power generation, industry, and agricultural sector [7] [8].

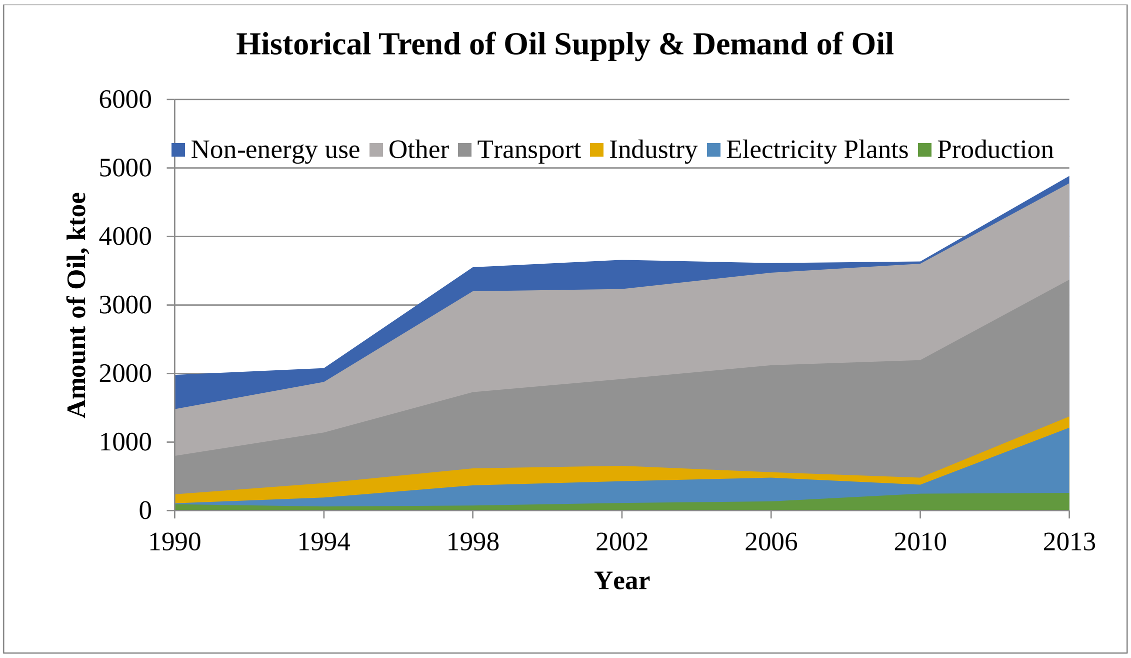


Figure 2-8: Historical trend of petroleum product consumption in different sectors [8].

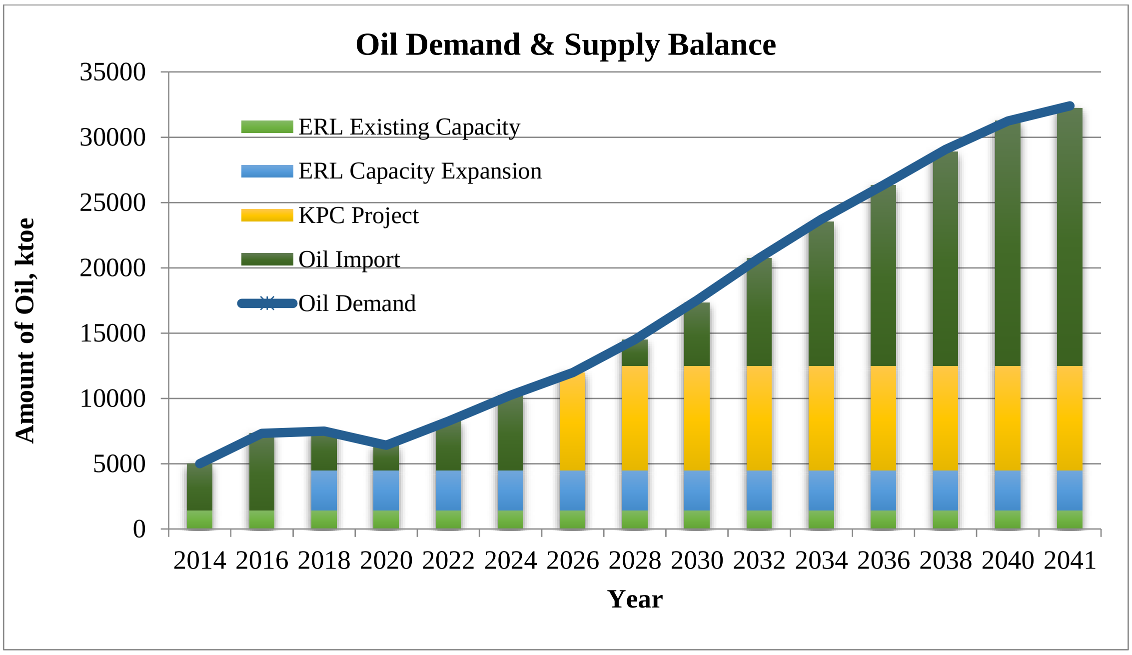


Figure 2-9: Total Oil Demand & Supply Projection [1].

Only public-owned Eastern Refinery Limited (ERL) has a capacity of 1.5 million tons per year [9]. Currently Bangladesh has an oil demand of 5.5 million tons, the remaining 4 million tons are met by imports. Crude Oil is imported mainly through foreign national oil companies (i.e. Saudi Arabia and UAE. Refined oil is imported through oil companies of Kuwait, Malaysia, UAE, China, Indonesia, and Thailand [10]. The oil demand forecast in Bangladesh is projected until 2041 as shown in Figure 2-9 [1].

Bangladesh is comparatively far behind of being dependent on its oil refinery comparing to annual oil demand which leads to being dependent on oil import. Oil refinery can secure oil supply in a great extent, especially in terms of a diversified crude supplier, various kind of crude oil processing capability in the refinery, freight cost savings due to benefit of using large crude oil tanker instead of smaller oil product market, less price volatility of crude oil comparing oil products and convenient quality speculation of crude oil.

2.2.5 LPG

LPG demand has increased by around 3.34% in the last 4 years in Bangladesh. This demand is around 7% out of total oil consumption, and 1% out of the total primary energy consumption. In total, the public and private sectors serve 553,622 MT of LPG. The public sector only processes 15,936 MT of LPG which is around 2.8% of total LPG consumption. Private companies fulfill the rest of the demand by import [11]. However, LPG demand is growing rapidly as an alternative to domestic cooking fuel and transportation fuel due to efficient burning, easy transportation, and cost-efficacy. The demand for LPG is projected to surge at the growth rate of almost 35% p.a., 15 times higher in 2041 than in 2016, as shown in Figure 2-10 [1]. Two LPG bottling plants having a capacity of 200,000 MT are planned to be set up in the coastal area to meet future demand [11].

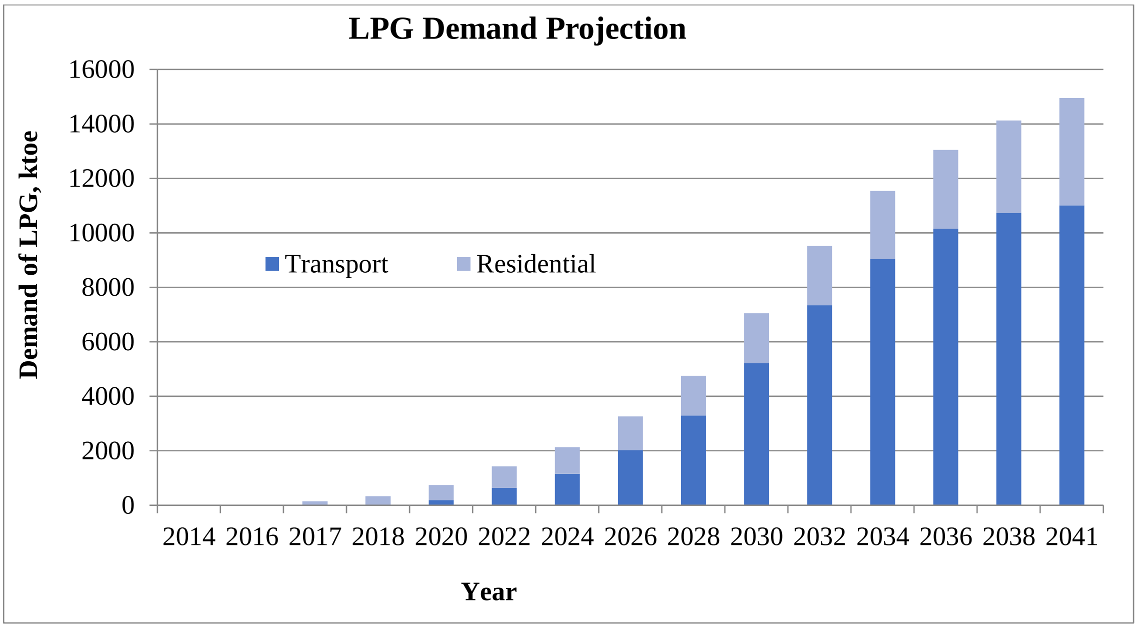


Figure 2-10: LPG demand projection [1].

Yet the prospect of LPG is fostering, some key issues need to be addressed by government, fixing the price gap between gas tariff and LPG or tariff between the public and the private dealer, for example. It is one of the major drawbacks to ensure uninterrupted growth. Besides, the strategic energy policy for LPG in Bangladesh is yet to be finalized.

2.2.6 Condensate and Natural Gas Liquids (NGL)

Condensate is a by-product of natural gas production and some of the gas fields located in the north-eastern part of Bangladesh contain a good percentage of condensate. 514,046 barrels of condensate were produced by the public sector and 3,805,245 barrels by private companies as a by-product of gas in 2018. Recovered condensate is fractionated to LPG, gasoline, kerosene, and diesel products and sold to National Oil companies and/or LPG Marketing Companies and private oil refining and marketing companies. In a total of 860,742 barrels of petrol, 353,104 barrels of diesel and 79,799 barrels of kerosene were produced by fractionating the condensate at the fractionation plants of government-owned companies. Moreover, another publicly held company extracted 24,720,000 liters of NGL from gas processed at Kailashtila [11]. Besides, Eastern Refining Limited produces 15,000-20,000 BPD of white oil products. It contributes 30-35% of white oil products that are supplied from the distillates of condensate [1].

2.3 Renewable Energy Potential in Bangladesh

Bangladesh has good potential for renewable energy especially for solar, hydro, biomass, wind, and biogas. According to SREDA's assessment, renewable energy potential in Bangladesh is approximately 3,700 MW (7,000 GWh per year). Among the different forms of RE potentials, at present solar and hydropower have the greatest power generation potential with biomass and biogas having some limited options [1]. Yet, biomass is the largest renewable resource in terms of primary energy usage due to its extensive use in heating or cooking. Currently, installed electricity generation capacity from renewable resources is 627 MW [12]. According to renewable energy policy, the Bangladesh government has a plan to achieve 10% of total energy share from renewable resources, which means 2000 MW power by 2020. The government has a plan to increase renewable power generation capacity to 24000 MW by 2021 and 39000 MW by 2030 [13].

Table 2-3: Renewable energy potential in Bangladesh [14]

Renewable Resources	Capacity, MW
Solar	2680
Wind	637
Biomass	275
Biogas	10
Municipal Waste	1
Mini Hydro	60
Mini Grid, Micro Grid Hybrid	3
Total	3666 or more

2.3.1 Biomass

In Bangladesh major biomass resource includes wood, agricultural residue, and animal waste. Agricultural residue and animal dung make a substantial contribution to biomass fuel. Converting biomass or animal waste into more energy-efficient fuel, for example biogas which can be used for cooking or electrification rural or isolated off-grid areas. Approximately 80,000 domestic biogas plants had already been installed throughout the country [11]. IDCOL had already completed 0.69 MW equivalent biogas to electricity plants. Additional 1 MW equivalent biogas to power generation project is under planning [15]. Rice husk also has good potential for power generation. IDCOL had installed two rice husk power plants with a combined capacity of 400 kW in Gazipur and Thakurgaon [16]. SREDA estimated the biomass power generation potential as 275 MW from rice husk and biogas potential equivalent to 10 MW [17]. The government of Bangladesh has targeted to install biomass power generation plant with a capacity of 30 MW and biogas plant with 2 MW by 2021 to fulfill the target of the National Renewable Energy Policy of 2008 to secure 10% power generation from renewable energy technology [18]. Municipal waste also has very good potential in Bangladesh due to the high volume of this waste, especially in Dhaka. The major limitation of this waste is the sustainable transportation of the material to the plant. If this challenge can be recovered, this waste can be turned into a sizable amount of energy. Two power plants with a combined capacity of 6 MW are under planning at Keraniganj and Narayanganj [6].

2.3.2 Solar

Bangladesh has a geographical advantage of having abundant sunlight, ranging from solar potential (4~7) kWh/m^2/day. On average 4~11 hours of sunshine is available all the year round except in rainy season from June to August. Solar PV technology has low energy-intensity and requires a large area of land. For Solar Home System (SHS), land availability is not an issue. It is growing popularity in electrification, solar irrigation in rural off-grid areas, solar heating, solar streetlight, and many more. SREDA estimated the solar rooftop potential (on-grid) as 634 MW and solar irrigation potential (off-grid) 545 MW [1]. IDCOL already installed and distributed SHS equivalent to 250 MW and solar irrigation system with total capacity of 30 MW throughout the country [11,19]. Besides, commercial solar projects require large areas of land and Bangladesh has limited land availability. 30 MW solar power generation, for example requires approximately 60 ha. of land (equivalent to 200 farmers’ farmland, an average Bangladesh small-scale farmer’s farmland is 0.3 ha.) [20]. To minimize the use of farmlands for solar projects, the solar park plan is limited to 2110 MW [21]. SREDA also installed rooftop solar including or excluding net metering equivalent to 53 MW [22-23]

Table 2-4: Current Solar projects [24-25]

Project Name	Capacity, MW
Solar Park	2110
Solar Rooftop System	54
Solar Irrigation	30
Solar Mini Grid	5.6
Solar Charging Station	0.3
Solar Home System	248
Solar Street light	10.6
Total	2458

2.3.2 Hydropower

Bangladesh is situated in a delta area along the Bay of Bengal. Most of the areas are lowland, lower than 9 m above sea level. It has relatively high rainfall northeast and southeast part of the country and abundant water resources, yet it has limited hydropower potential. A study conducted in 1981 showed Bangladesh has 1500 GWh/year potential of hydropower at Kaptai, Matamuhuri, and Sangu river [11]. Karnafuli hydropower plant, the only hydropower plant in Bangladesh utilizes the water of Kaptai Lake. This plant has an installed capacity of 230 MW. Hydropower (HP) Potential and its development plan can be defined in two sections, for example, Small Hydropower Potential Sites (SSHP) in plain land and ordinary HP potential sites in Chittagong hilly area.

The study had been carried out on 20 sites outside of Chittagong. Most of the potential sites showed relatively small hydropower potential from ten to 200 kW, which might be successful as micro hydropower projects for storage dam or canals for irrigation. In Chittagong hilly area, another study had been performed extensively on Sangu, Matamuhuri, and Bakkhali river basin by MPEMR to find potential sites for hydropower development next to Kaptai hydropower plant. This study identified 18 sites in total; ten sites in Sangu, five sites in Matamuhuri, and three sites in Bakkhali. Capacities of these potential sites might vary from 0.1 MW to 20 MW [1,17]. Key potential sites with capacity are enlisted in Table 2-5.

Power generation in these sites might also vary with the amount of annual precipitation. Water quality, especially arsenic concentration, the salinity of underground water of these rivers are important factors that need to be considered before implementing any project. The social and environmental impacts also need to be assessed before launching any project.

Table 2-5: Key hydropower potential sites [1,17]

Type of Hydro project	River	Location	Cumulative Power, MW
Ordinary HP potential sites in Chittagong	Sangu	J33, J34, J39, J42, J45, J47, J52, J53, J61, J66	55.42
	Matamuhuri	J12, J13, J17, J23, J31	3.44
	Bakkhali	J11, J14	0.23
SSHP potential sites outside of Chittagong	Teesta	Canal Mile23 and Barrage	6.2
	Rangpur	Canal Mile 7, 19, 33	3.7
	Bogra	Canal Mile7	2.7

2.3.3 Wind

Currently, Bangladesh has two wind power plants having a capacity of 2.9 MW in coastal areas at Feni and Cox's Bazar. To explore more wind potential inside the country, wind mapping or wind resource modeling was performed by USAID and NREL of the U.S. from 2014~2017. This study found Bangladesh has a potential of over 30,000 MW throughout the country excluding already developed land, environmentally sensitive land, and land unsuitable for other reasons [26]. SREDA had initial planning to launch a wind park project with a capacity of 650 MW [17]. Currently, implementation is ongoing for two wind projects with a capacity of 32 MW wind power plant at Sirajganj and Feni. Another two projects with a combined capacity of 70 MW in Cox’s Bazar and Patuakhali are under planning [27]. Implementation of one hybrid solar-wind off-grid project with capacity 7.5 MW is also ongoing at Noakhali [17]. The government has the intent to launch up to 400 MW wind project by 2030 [18].

2.4 Energy Modeling

2.4.1 Introduction

The objective of energy modeling is to develop a support method to analyze a project to understand the impacts and outcomes in terms of measurable indicators to make a concrete decision. Energy model assessment before implementation can be promoted in a region having rapid economic growth. This process includes a projection on future energy demand and supply by measuring the impact of different energy systems. Recently lots of energy models are available due to the rapid increase of software options. These models are designed to serve multiple purposes which might be challenging while selecting the most suitable option for a certain purpose or situation.

2.4.2 Classification

The classification concept can give insights into similarities and contrast between models and promotes the selection process. Myriad classifications are available, but none of them can be claimed best. A different model can serve best for a different purpose. Since the purpose of these energy models is different, it made the classification arbitrary.

EFOM-ENV (Energy Flow and Optimization Model–Environment) is programmed in Fortran and covers the complete energy system of a country. GAMS (General Algebraic Modelling System) version of EFOM-ENV is developed to improve the convenience, flexibility, and portability. The modeling language of EFOM-ENV/GAM is specially developed to handle large and complicated models for scenario development and policy analysis. In this model, all energy processes are organized with a hierarchical structure. Therefore, a similar type of energy processes can be grouped together, so that a clear structure of the energy system is realized [28].

ENERPLAN software package provides users both macroeconomic and energy sector models. Two models can also be done independently. The programing used is this software is user friendly and flexible to the level of detail according to user preference. It conducts econometric analysis to determine model coefficients with historical data as input variables. Outputs from the model can be represented in a graphics module. The main strength of this approach is estimating the macro-economic model [29].

Table 2-6: Energy model classification [31].

Features	EFOM-ENV	ENERPLAN	ENPEP	LEAP	MARKAL	MARKAL-MACRO	MESAP	MESSAGE-III	MICRO-MELODI	RETScreen
Purposes: General Purpose	√	√	√	√	√	√	√	√	√	√
Specific Purpose	√	√	√	√	√	√	√	√	√	√
Features	EFOM-ENV	ENERPLAN	ENPEP	LEAP	MARKAL	MARKAL-MACRO	MESAP	MESSAGE-III	MICRO-MELODI	RETScreen
The Model Structure: Internal and External Assumptions	Depends on mode	Depends on mode	√	√	√	√	√	√	√	√
Analytical Approach: Top-Down vs. Bottom-Up	Top-Down	Top-Down	Both	Both	Bottom-up	Both	Both	Bottom-up	Top-Down	Bottom up
Underlying Methodology	√	Depends on mode	√	√	√	√	√	√	√	√
Mathematical Approach	√	NA	NA	NA	√	√	√	√	√	NA
Geographical Coverage	National	National	National	Global	National	National	National	National	National	National
Sectorial Coverage	Energy Sector	Energy Sector	Entire Economy	All sector	Energy Sector	All sector	All sector	Energy Sector	Energy Sector	Energy Sector
The Time Horizon: Short, Medium, and Long Term	Short to medium	Short to medium	Short, medium, long	Short, medium, long	Medium to long	Medium to long	Medium to long	Short, medium, long	Medium to long	NA
Data Requirements	√	√	√	√	√	√	√	√	√	√

ENPEP-BALANCE (Energy and Power Evaluation Program) is modeling software that finds possible options to meet the energy demand with available resources and technologies. In this method, a network is designed that shows the flow of energy from primary resources to the final form of energy for end-users. It evaluates the impact of each segment of this design of the energy system by changing price and demand levels. It also finds the intersection point of supply and demand curves for all forms of energy supply. This software is extensively used globally to perform greenhouse gas mitigation analyses, energy policy assessment, and market analyses [30].

LEAP (Long-range Energy Alternatives Planning System) is a software tool globally used for analyzing energy policy and climate change mitigation. It performs integrated resource planning, mitigation assessment of Greenhouse Gas (GHG), and prepares Low Emission Development Strategies (LEDS). It has been used as a standard in many countries, especially the developing ones. It can also estimate energy consumption, analyze production and resource extraction for all sectors of a region or a country [32].

MARKAL is a generic model that represents the evolution of the energy system over the years at the local or national level. The word MARKAL is originated by combining two words (MARKet and ALlocation). This software is used to analyze energy and environmental policy. This model can find the least cost solution options to meet the energy demand and prepares cost-effective solutions for GHG reduction. Various input parameters such as energy demand, resource costs, capacity factors, and so on, are inserted from which software calculates an optimal technology mix to meet the demand at minimum cost [33].

MARKAL-MACRO software is created by combining two models which results in a single, independent new model. MARKAL model has the capability of detailed technological design, whereas MACRO model performs that in a succinct method with optimal growth general equilibrium model. This new model has the characteristics of a general equilibrium model while maintaining rich technological features of MARKAL. The equilibrium assumes perfectly foresighted competitive markets in a sense of neo-classical economic theory [34].

MESAP (Modular Energy System Analysis and Planning Environment) is a modeling tool that analyzes energy-systems with planning network (PlaNet). Analysis and simulation of energy demand, supply, economic and environmental impacts for local, regional, and global energy-systems are performed by PlaNet which is a linear network module of MESAP. It calculates energy savings and emission mitigation comparing with any reference energy systems. The model approaches with technology-based modeling including several competitive technologies demonstrated in parallel processes [35].

MESSAGE offers an optimization model that can be used to plan medium to long term energy policy, analyze climate change impact, develop possible models for the national or global system. This model takes 5 or 10 year time-step as a reference to simulate for 120 years. It can simulate all thermal generation processes, renewable technologies, carbon sequestration, storage, and conversion system and transport technologies. It can also calculate economically attractive options for GHG emission reduction [36-37].

RETScreen is modeling software that can analyze clean energy projects for energy performance, renewable technology, and cogeneration project feasibility. This software was originally developed with a combined effort from the government, industry, and academia by Natural Resources Canada in 1996. It offers the opportunity to planners and decision-makers to determine, evaluate, and optimize technical, and financial feasibility of potential clean energy projects. This tool also enables managers to identify and confirm the performance of their plants and help them to find energy-saving options. Energy production and savings, economic analysis, emission reduction analysis, financial feasibility with multiple criteria assessment options for clean energy technologies can be explored globally with this software [38]. A summary of the modeling characteristic is included in Table 2-6.

2.4.3 The Choice of Energy Models for Energy Planning

To understand which energy model is most suitable to support local energy planning for a developing country, it is important to choose the relevant energy systems that can meet the required forms of energy. Impacts or outcomes and limitations of the energy system also need to be considered. According to which criteria, the energy systems should be assessed is also an important factor before choosing energy models. For each of these issues, a different energy model can be chosen.

2.4.3.1 ***Energy Demand***

In a rapidly growing economic region, historical data may not provide a reliable forecast. Due to rapid growth, change in pattern might result in the historical trend. Therefore, scenario analysis is more suitable. Certainly, previous experience in that region that also experienced rapid economic growth, can serve as a basis. It is important to know what forms of energy (e.g., heat, electricity, and transport fuels) are in top demand in that region. Which purpose this energy would be used, should also be considered. Desired energy services should be the starting point of the analysis which indicates a bottom-up approach rather than a top-down one for a detailed and explicit analysis.

2.4.3.2 Energy Supply Systems

Primarily, the selection of an appropriate energy system is the main concern. Hence, the energy model must have a bottom-up approach for available technologies to convert conventional resources, for example oil, coal, natural gas, and other available renewable resources, such as solar, wind, hydro, biomass, and so on.

2.4.3.3 Impact Assessment

Most of the energy models perform impact analysis on technical, financial, and economic aspects. Nowadays an environmental impact assessment is also done which demonstrates environmental impact in quantitative terms. Qualitative social impacts may play a critical role in the viability of an energy system. Hence, those models offer impact models with a multi-criteria approach, having both quantitative and qualitative data, are preferred. Undeniably this multi-criteria approach confirms the assessment of the energy options based on all relevant criteria or preferences of the energy planner.

2.4.3.4 Appraisal

An appraisal is a multiple criteria analysis including quantitative and qualitative evaluation. One major aspect of appraisal is the sensitivity analysis of the outcomes to small changes in important input variables. The sensitivity analysis might result in the number of changes in outcome due to a range of changes of input variables indicating the vulnerability or strength of a project. It is important to know how the values of one criterion are affected if another criterion is altered. This will help to make the most appropriate decision with lucid overview among different options and its consequences.

A flexible model is considered as the most reliable methodology because it considers maximum adjustment to local circumstances. For example, RETScreen is a clean energy modeling tool that can be used to make this kind of analysis. This software assists decision-makers to understand the project performance, feasibility, and impact to choose the best option. It can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability, and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). Moreover, it offers a bottom-up approach of analysis with options for power generation, heating, cooling, cogeneration forms of energy conversion cases. This study mainly focused on power generation from available renewable resources of Bangladesh. This software also comes up with an impact assessment platform for technical, financial, economic, and environmental analysis. It also offers appraisal or multiple criteria analysis with optional sensitivity and risk assessment. All these features of RETScreen software perfectly match with the scope of this study.

2.5 Discussion on National Energy Policy

Primary source of fossil reserve in Bangladesh is natural gas, coal and small amount of oil. These three resources play a vital role in energy conversion and power generation to fulfill the increasing energy demand of Bangladesh according to national energy policy. Currently approximately 58% of total power comes from natural gas. Considering the significance of electricity on its own growing economy, government had decided to maximize the use of natural gas in electricity generation. Besides, production of chemical fertilizer from natural gas is not economically profitable as fertilizer are supplied at a very cheap rate to support the agriculture. It is also not economical to use natural gas as a feedstock to produce petrochemicals compared to hydrocarbons obtained from extraction and purification of crude oil. For these reasons, utilizing natural gas for chemical fertilizer and other petrochemicals are strategically limited. Oil reserve in Bangladesh is very negligible. Moreover, oil demand is surging in transportation and industrial sector. This demand is mostly met by importing crude oil and different petrochemicals. Rigorous exploration at deeper sub-surface needs to be launched to realize the oil resource. Additionally, Bangladesh has notable amount of coal deposit in the northwestern region. As natural gas is depleting, imported oil and coal will strategically meet the extended need. Several coal-based power plant and coal mining activities are ongoing for effective energy management and reduce the dependence of natural gas or import of oil [39].

As fossil fuels are expending, alternative source of energy, for instance, renewable sources are mainly focused to meet extended energy demand in upcoming years. Even though natural gas, oil and coal are planned to be the primary source of energy, alternative fuels, for example, solar, biomass, small hydro and wind sources are targeted to be explored more for power generation. Organized and planned renewable source conversion to power generation in terms of location selection or pre-planned installation capacity according to the resource availability would increase the scope of efficient energy conversion. Rural area gets priority in terms of alternative fuel technology as expansion of central grid is expensive to those areas. Additionally, further exploration for oil or natural gas reserve will be ongoing. To implement these clean technologies government needs external financial assistance and funding from private organizations which is challenging. Extended effort should be offered to collaborate and get assistance from different international institutions, non-government organization, research firm [39].

There are several important features to have an effective national energy policy. It must include specific roadmaps to achieve the goal considering all relevant factors and variables. Bangladesh is heavily dependent on fossil fuel for power consumption and transport sector. Transition from fossil fuel to renewable energy is a big challenge for several reasons, which includes limited potential of renewable energy, low energy conversion, high capital cost and so on. National energy policy of Bangladesh needs to have a comprehensive roadmap for smooth transition from fossil fuel to a targeted percentage of renewable energy. An exact quantification of renewable potential can be a starting point to achieve this milestone. Additionally, there is no plan or statement to promote renewable energy in the national energy policy. More efforts are required to explore and identify the best use of renewable potential in terms of technology, location and capacity. Relevant knowledge sharing and best practices can also be adopted from other countries or organizations. National energy policy of Bangladesh has scope to include these features to make it more persuasive. Awareness raising programs, trainings and collaboration of stakeholders can support this progress. Climate change policy is also not incorporated in the nation energy policy that would have a specific target to reduce the GHG emission. It might also include Low Emission Development Strategy (LEDS).

Moreover, identifying gaps and yearly review of the policy can also accelerate the progress and make the policy worthwhile. A revised version of policy can be generated and published yearly which includes a study identifying gaps between the target and the achievement. Encouraging investors to launch more clean energy projects through financial benefits or incentives or tax advantage can also expedite the overall process. Net metering or feed metering can also be introduced to encourage the solar power generators.

2.6 Concluding Remarks

Bangladesh is a developing country having a rapidly growing economy. Energy demand is also growing in the same manner. Hence, a good projection of demand is critical. Feasibility analysis with projected need is most important to have a good supply and demand balance in the coming days. In this study, energy modeling in RETScreen was done for potential clean energy technologies in Bangladesh. Multiple impact (technical, financial, economic, environmental, sensitivity) analysis tools are provided with a software to understand the quantitative and qualitative outcomes. This analysis might help planners and decision-makers to immediately identify, assess, and optimize the technical, financial, environmental viability of potential clean energy projects. Multiple potential projects can be easily compared and based on that most favorable one can be chosen for implementation.

It also expedites information sharing in a standardized, internationally recognized platform. To make the best choice for a country, it is inevitable to make a similar analysis with multi-dimensional scopes. This kind of analysis can be done for local or country wise energy projects before making a concrete decision which might have long term effects on the overall economy before finalizing the energy policy. RETScreen provides valuable information about clean energy technologies and builds awareness of its capabilities and diverse execution. It develops a good sense of knowledge which might be considered as an excellent resource for skill development and information dissemination [40].

3. METHODOLOGY

3.1 Introduction

This chapter describes the methodology used for the current study. An energy management software developed by CanmetENERGY, RETScreen 4, was used for developing the energy conversion models. Each model consists of a renewable primary energy (e.g., biomass, solar, hydro, and wind) as the input and electricity as the product. The approach used for modeling and analysis of these energy systems is shown in Figure 3-1.

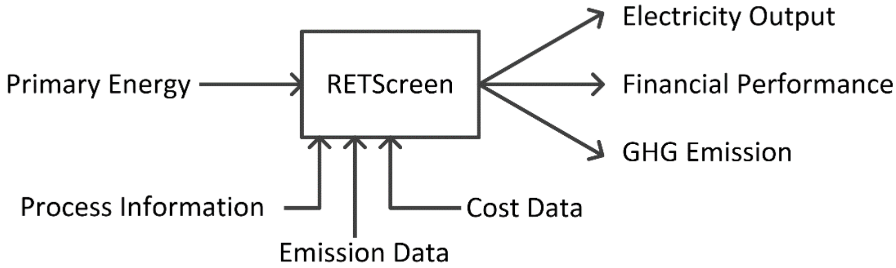


Figure 3-1: Primary energy to electricity model in RETScreen: inputs and outputs

Two methods are available to perform energy modeling in RETScreen, namely Method 1 and Method 2. Method 1 includes proposed case information, summarized GHG performance, and financial analysis, and generally used to make a pre-feasibility analysis with fewer input parameters. Method 2 is used for more detailed analysis. It consists of six features: project and climate database, energy model with equipment and technology selection, cost analysis, emission analysis, financial analysis, and risk analysis. For this study, Method 2 was used for all energy conversion models.

The following sections include brief discussions on the modeling, analysis, and interpretation of renewable energy systems in RETScreen using method 2.

3.2 Standard Analysis of Energy Systems in RETScreen

RETScreen can be used to evaluate the feasibility, energy conversion or savings, economic viability, greenhouse emission effect, and risk assessment for the renewable energy project [41–43].

RETScreen software offers a platform to compare conventional technology and proposed clean energy technology. The energy model in RETScreen includes five steps of standard analysis. Inputs to the energy models and analysis are performed using Microsoft Excel; each of the five steps mentioned above are associated with each other. Figure 3-2 represents a flow chart of the five-step standard analysis in RETScreen [40].

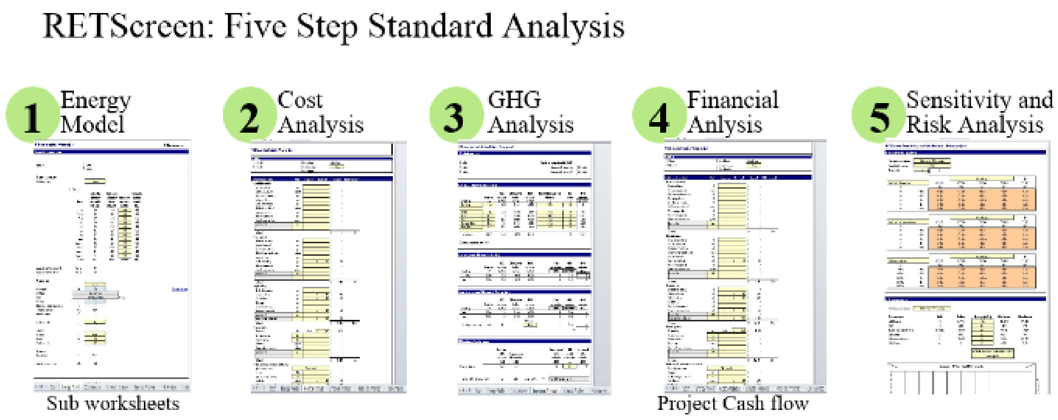


Figure 3-2: RETScreen model standard analysis steps [40].

3.2.1 Step 1: Energy Model

The energy model specific data are provided in the first step. The user provides project information including the location, model type, and technical details of the intended energy project. The technical details include: type of technology in use, equipment type, capacity, efficiency, availability, etc. Based on the use inputs the annual energy production, capacity factor, and electricity exported to the grid are calculated in this step.

3.2.2 Step 2: Cost Analysis

In the second step, capital cost, fixed and variable operating and maintenance costs are inserted in cost analysis worksheet. From this data, the model calculates initial, annual, periodic costs, annual savings, and several financial indicators for the proposed case system. There are two available options at this step: Method 1 and Method 2. To perform cost analysis with method 1 (pre-feasibility analysis), only major costs need to be inserted whereas, in method 2, details cost in the different head can be added.

3.2.3 Step 3: Greenhouse Gas (GHG) Analysis

This analysis compares emission generated from the proposed technology to a user-defined base case. There are three analysis options to choose: simplified, standard, or custom. The GHG emission reduction potential is calculated by finding the difference between GHG emissions of the base case and the proposed case.

3.2.4 Step 4: Financial Analysis

In this step, the user defines relevant financial parameters associated with the proposed clean energy project, for example, project life, inflation rate, electricity export escalation rate, debt ratio, debt term, income tax, depreciation rate, incentive or grants (if any), GHG emission reduction credits and discount rate. Based on this data, the model estimates a set of financial indicators, for example pre-tax Internal Rate of Return (IRR), after-tax IRR, net present value, benefit-cost ratio, energy production cost, and GHG reduction cost to evaluate the feasibility of the project. A cumulative cash flow diagram is also generated in this worksheet.

3.2.5 Step 5: Sensitivity and Risk Analysis

This worksheet contains the Sensitivity Analysis, and the Risk Analysis sections. Each analysis gives information on the relationship between key input parameters and the financial indicators and shows the impact factors of these parameters in descending order. Sensitivity analysis and risk analysis are performed on after-tax IRR, Net Present Value (NPV), and ROI, for sensitivity range of 20% and threshold limit of 15%. A threshold limit represents the maximum limit to allow the increase of the cost. The cost should not exceed beyond to avoid financial infeasibility.

3.3 Model Description

Energy models with four renewable energy resources as input have been developed. These include biomass power models, solar photovoltaic systems, wind power models, and small-scale hydropower plants. A summary of the models considered for the study is given in Table 3-1.

Table 3-1: A brief description of RETScreen models [17,26].

Model type	Model features	Probable Location	Lifetime in year
Biomass	1 MW Gas Turbine Single Cycle Gas Turbine, Steam Turbine and Gas Turbine Combined Cycle Power Plant with Single fuel/fuel/Dual fuel (Biomass 50%-Diesel 50%)/Dual fuel (Biomass 75%- Diesel 25%)	Dinajpur	20~30
	2 MW Gas Turbine Single Cycle Gas Turbine, Steam Turbine and Gas Turbine Combined Cycle Power Plant with Single fuel/fuel/Dual fuel (Biomass 50%-Diesel 50%)/Dual fuel (Biomass 75%- Diesel 25%)	Dinajpur	20~30
	5 MW Gas Turbine Single Cycle Gas Turbine, Steam Turbine and Gas Turbine Combined Cycle Power Plant with Single fuel/Dual fuel (Biomass 50%-Diesel 50%)/Dual fuel (Biomass 75%- Diesel 25%)	Dinajpur	20~30
Solar	5 kW Solar Photovoltaic model	Dinajpur	30
	250 MW Solar Photovoltaic model	Dinajpur	30
Wind	1 MW Wind Power plant	Chittagong	20
	5 MW Wind Power plant	Mongla	20
	50 MW Wind Power plant	Cox’s Bazar	20
Hydro	1 MW Small Scale Hydropower Plant (SSHP) J17	Matamuhuri River	30
	20 MW Small Scale Hydropower Plant (SSHP) J39	Sangu river (Chittagong)	30

3.3.1 RETScreen Model for Biomass to Power

Biomass to power energy models of several capacities (1 MW, 2 MW and 5 MW) have been considered. The technologies to convert biomass fuel to electricity Considered include gas turbine single cycle, steam turbine single cycle and gas turbine combined cycle with a steam turbine.

Fuel options considered for the models include:

- Single Fuel
- Multiple Fuels (50-50 biomass-diesel and 75-25 biomass-diesel)

3.3.1.1 **Energy Model**

RETScreen software can calculate annual energy production with the help of technical data, inserted in the energy model. Technical data—technology type, equipment data, capacity, availability, fuel type, fuel rate, efficiency, heat rate, electricity export rate—need to define the energy model. RETScreen software incorporated a wide range of product data with its performance and specification. This inbuilt data was used to specify the models of proposed clean energy technology, which entails minimal data requirements. It also results in fast, accurate analysis with custom-developed methodologies.

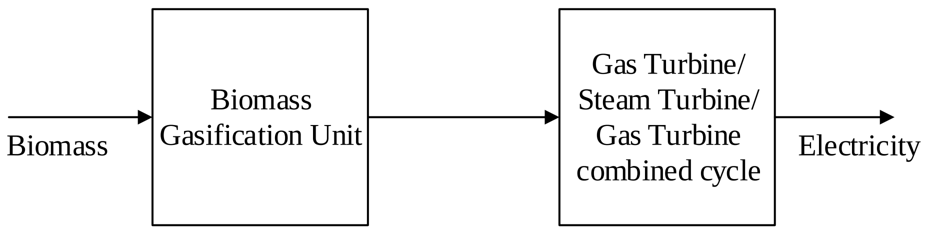


Figure 3-3: Biomass to electricity model in RETScreen

Four RETScreen models are designed for biomass to generate electricity with capacity: 500 kW, 1 MW, 2 MW, and 5 MW, for instance. For these models, the feedstock is an important parameter, is usually selected based on availability. Most available biomass feedstock in Bangladesh is forest residues, wood waste, agricultural waste. These are considered as raw materials for this model. Heat rate is another important input parameter that defines the efficiency of the feedstock. The heat rate is the amount of energy used by an electrical generator/power plant to generate one kilowatt-hour (kWh) of electricity. For biomass, heat rate can largely be varied with different types of biomass and its moisture content. Heat rate is considered an average of 13,648 Btu/kWh for Bangladesh [44]. The cost of raw material also varies depending on the type of biomass feedstock, the average cost of biomass feedstock is approximately $118/ton[45]. The current electricity export rate is $70/MWh in Bangladesh [6].

Availability can be defined as a capacity factor, which is approximately 85% for a biomass power plant in Bangladesh [46]. There are several techniques for biomass conversion from biomass feedstock to gas turbine or steam turbine—gasification, combustion, pyrolysis, anaerobic digestion—commercially gasification is proven to be the most effective one.

Industrial-scale (1-250) MW gas turbine combined cycle efficiency can approach 60% or more, whereas single cycle gas turbine efficiency is approximately 40%. Modern large capacity steam turbine has higher overall efficiency, often more than 40%, smaller size steam turbine exhibits lower efficiency around (15-35) % [47].

For each model, single fuel or multiple fuels in terms of period or percentage can be chosen. Feasibility was also checked for multiple fuel facility with two options (50-50 biomass-diesel and 75-25 biomass-diesel). Currently, the fuel rate for diesel is $0.765/L in Bangladesh [48].

3.3.1.1 Cost Analysis

The capital cost of biomass power plant with gas turbine was considered around $3605/kW, usually varies in a range of (2500-5000) $/kW [49]. Fixed operation and maintenance (O&M) cost was assumed as around $81/kW/yr, which might vary within a range of (45-92) $/kW/yr, whereas variable O&M cost varies (6-13)/kW. In a steam turbine, the capital cost was considered $1279/kW [50]. Fixed O&M cost was approximately $0.01/kWh of electricity produced [51]. Gas turbine combined cycle for biomass power plant capital cost was approximately $3266/kW, which might vary in a range of $(2500-4000)/kW. Fixed O&M cost was presumed $48/kW/yr and variable O&M cost $4/MWh [49]. The debt ratio was assumed 70% and the debt interest rate 10.2% for power generation from biomass [46]. Effective income tax is 25% and 100% tax holiday is currently allowed for 5 years for renewable projects in Bangladesh [52].

3.3.1.2 GHG Emission

For detailed emission analysis in RETScreen, method 2 is selected, as it allows users to customize base case fuel type and percentage of its contribution to total power generation. The average efficiency of each fuel type was also inserted. To make the comparison more specific and authentic, a base case electricity system with an existing fuel mix of Bangladesh was considered in emission analysis worksheet. According to most recent data published by BPDB, power generation based on fuel contribution is 57.37% from natural gas, 25.16% from furnace oil, 7.23% from diesel, 2.76% from coal, 1.21% from hydro, 0.16% from solar and 6.12% from import used as a base case fuel mix [6].

This aforementioned software calculates GHG emission factors for the base case and proposed case. From the difference of these values GHG emission reduction is calculated. GHG emission factors for methane and nitrous oxide are considered along with carbon dioxide for emission reduction calculation. Later, the software converts the emission factor of methane and nitrous oxide to carbon dioxide as a common currency for sum up and comparison. This conversion is done considering the equivalent carbon dioxide emission potential according to the Global Warming Potential (GWP). RETScreen used inbuilt value of GWP of carbon dioxide as 1, methane as 25, and nitrous oxide as 298 [53].

A carbon credit is an attempt to reduce GHG emissions with a trading approach by generating credits. It can be defined as a credit for greenhouse gas emission reduction or removal through a project operated by government, industry, or organization to compensate for the emission they are generating with the process. This software deemed the implementation of carbon credit finance following the Kyoto Protocol. A percentage is paid each year as a transaction fee to the crediting agency, United Nations Framework Convention on Climate Change (UNFCC), or the host country of the project. Usually, this fee is utilized to fund projects or process development associated with carbon dioxide mitigation or removal. GHG credit transaction fee is 2% according to the rate specified by UNFCC [54].

Electricity transport to the central grid associates with transmission and distribution loss. In an electric system, it is an amount of electricity that is lost mainly as heat during transmission and distribution in the system. This loss was considered 12% [3].

3.3.1.3 **Sensitivity and Risk Analysis**

Sensitivity analysis with RETScreen software is simple and straightforward. The main objective of this analysis is to understand the level of impact of the input parameter to financial outcome. It calculates the impact of the financial feasibility indicator by varying two input parameter values within a given range and represents the result in a tabular form. This analysis was performed for biomass models on after-tax IRR equity considering a 20% sensitivity range and 15% threshold value.

Several types of photovoltaic cells are available now. Among them, the efficiency of monocrystalline silicon (mono-Si) cell is highest, around 16% [55]. Due to its higher efficiency and performance, the mono-Si type of PV cell is selected for these analyses. To match the voltage and frequency of the central grid, an inverter is connected, which converts the DC output of the solar PV array to AC output. The inverter has efficiency around or above 90% at medium to high irradiance level [56].

3.3.2 RETScreen Photovoltaic model

RETScreen uses simplified algorithms to minimize data input requirements and speed up the calculations while maintaining an acceptable level of accuracy. Solar PV model having electricity exported to central-grid, is simple and straightforward compared to the off-grid model. The algorithm is based on assumed average electricity generation capacity from solar. The battery is designed to provide the rest of the load that solar cannot serve especially in blackout days.

RETScreen photovoltaic model is designed for 5 kW equivalent to support a standard home and 250 MW as an industrial scale considering the solar potential in Bangladesh. These models are designed to analyze the feasibility of energy production and financial performance for small scale and industrial scale for central grid application. The user specifies general parameters to define the solar PV model including monthly or annual load. This model measures the annual solar radiation on horizontal and tilted PV array for any location using monthly average solar radiation values [40].

3.3.2.1 **Energy Model**

Two RETScreen models had been designed for power generation to utilize the solar potential in Bangladesh: 250 MW industrial-scale central grid solar PV model and 5 MW small scale solar PV model for a standard home. The location of the solar PV plant is an important factor, as solar radiation varies from place to place. For these models Dinajpur is selected as a primary location due to its largest horizontal solar radiation value, average 4.99 kWh/m^2/day inside Bangladesh according to inbuilt meteorological data in RETScreen from NASA. Average tilted daily solar radiation is 5.46 kWh/m^2/day for this place. A solar tracking system is another major parameter. It is an advanced technology to maximize the solar radiation reception by automatically orienting the solar panel towards the sun. The orientation of the panel changes towards maximum solar beam by rotating around one axis or more precisely around two axes. Energy absorption efficiency increases by approximately 40% with two axes solar tracking systems [13]. However, these models were designed considering fixed solar tracking system as it is the most common type. The current electricity export rate is $70/MWh in Bangladesh according to BPDB [3].

3.3.2.2 **Cost Analysis**

Capital cost for solar PV systems may vary between $1,500/kW to $2,000/kW. This cost was assumed $2000/kW for a 5 kW solar PV model and $1500/kW for 250 MW model, as cost per unit kW increases for small size plan rather than the larger one. Fixed O&M cost was presumed as $12.5/kW/yr for both models and variable O&M cost as zero [49]. Project lifetime was considered 30 years [49]. Debt interest rate is 10.2%, debt ratio 70%, and the debt term is 10 years for both solar PV models [46]. Effective income tax is 25% and 100% tax holiday is currently allowed for 5 years for renewable projects in Bangladesh [52].

3.3.2.3 **GHG Emission**

Emission analysis of each solar PV model was performed using method 2 for detail analysis following a similar methodology as illustrated in section 3.3.10. The same fuel ratio contributing national power grid was used as the base case in this analysis along with the average electricity generation efficiency of each fuel. Transmission and distribution loss was also considered as 12% for both models as mentioned earlier [3]. GHG credit transaction fee is 2% [54].

3.3.2.4 Sensitivity and Risk Analysis

Sensitivity analysis was performed on after-tax IRR equity considering a sensitivity of 20% and a threshold value 15%. In this analysis, fuel cost and debt interest rates are individually varied with respect to initial cost in a range of ±20%, and impact on after-tax IRR equity is represented in percentage.

3.3.3 RETScreen Wind Energy Project Model

Wind energy project model can be designed using RETScreen software to estimate the energy production, annual savings, capital costs, and greenhouse gas emissions reduction for central-grid, isolated-grid, and off-grid wind projects. It can be designed for a wide range of dimensions from large scale multi turbine wind farms to small scale single turbine systems.

The energy model consisting of equipment data and technical details are completed first. Cost analysis worksheet is then carried out with the capital cost, annual cost, and periodic cost, and followed by the financial analysis worksheet. This process can be repeated several times to help optimize the design of the wind energy project from an energy use and cost standpoint [40].

3.3.3.1 ***Energy Model***

Location selection having good potential is one of the most important factors before starting a project. Modeling of wind resource to assess the potential was done in nine sites. Chittagong (Sitakunda), Mongla, and Cox's Bazar (Parki beach) have the maximum potential. Among these locations, Cox's Bazar was considered for RETScreen models with capacity 1 MW, 5 MW, and 50 MW to compare the site potential in different scale. To make the analysis more accurate, method 3 was chosen for each model in the energy model worksheet which requires more specific data insertion. Monthly wind speed with measuring height was inserted in this analysis to specify the wind potential for each location in each model [26]. Capacity was specified from the RETScreen product database along with the number of turbines and hub heights. The miscellaneous loss was assumed 5% [40]. Availability or capacity factor is another important parameter that validates the wind potential of the specific site. This value fluctuates from time to time; however, the average value remains almost constant over a long period. The average availability is considered approximately 60% [57].

3.3.3.2 ***Cost Analysis***

Major costs involving wind projects are capital cost, fixed and variable O&M cost that were inserted in the cost analysis worksheet of each model. The capital cost of wind model was considered as $1500/kW for all models, whereas usually it varies in a range of $1270~$2860. Fixed O&M cost for wind power projects is approximately $(15~38)/kW.yr depending on the type of wind turbines and others cost. This value is presumed as $20/kW.yr for all models. Variable O&M cost ranges between $(6~12)/MWh. And this value is considered as $8/MWh for all models. This analysis expects 20 years of project life [49]. Debt ratio of 70% and debt interest rate 9.7% are assumed with debt term of 10 years [46]. Effective income tax is 25% and 100% tax holiday is currently allowed for 5 years for renewable projects in Bangladesh [52].

3.3.3.3 ***GHG Emission***

As previously mentioned in section 3.3.10, fuel mix contributing total power generation was inserted along with fuel wise electricity generation efficiency. T&D loss was also considered 12% [6]. GHG credit transaction fee is 2% [54].

3.3.3.4 ***Sensitivity and Risk Analysis***

Sensitivity analysis is performed by calculating a change of percentage of the output parameter, for example, after-tax IRR-equity, NPV, after-tax asset, equity payback due to changes in two input parameters. Important input parameters, for instance, the fuel cost of the base case or fuel cost of the proposed case, or debt interest rate are changed individually with initial cost in a range of ±20%. Due to this change in both input parameters, the changes of after-tax IRR-equity is calculated, and the results are shown in a tabular form in sensitivity analysis worksheet.

3.3.4 RETScreen Small Hydro Project Model

RETScreen model can be designed for a large, small or, microscale hydro project with a central-grid or off-grid option. It includes options for choosing both run-of-river (a hydro plant that uses the only natural flow of the river) and reservoir developments incorporating sophisticated formulae for calculating efficiencies of a variety of hydro turbines. The Small Hydro model can be used to evaluate small hydro projects typically classified under the following three names:

- Small hydro (1 MW to 50 MW)
- Mini hydro (100 kW to 1 MW)
- Micro-hydro (less than 100 kW)

Six worksheets consist of Energy Model with hydrology analysis, load calculation and equipment data, Cost Analysis, Emission Analysis (GHG Analysis), Financial Analysis and Sensitivity, and Risk Analysis. These analyses actuate the feasibility analysis of the hydro project in RETScreen software. For detail technical analysis of the hydro project, it needs specific hydrological information from available topographic maps or previous hydrologic assessment. If hydrological data is unavailable or detailed mapping is unknown, a general feasibility analysis can be performed with basic information of known hydro potential of that site. In the case of a central-grid model, the energy conversion is equal to the energy available. The off-grid application procedure is slightly more complicated and involves both the power-duration curve and the load-duration curve for feasibility analysis [40].

3.3.4.1 Energy Model

The selection of location having good potential is the most important step to plan a hydro project. Hydropower potential had been identified in several locations of Sangu Matamuhuri, Bakkhali, and Banskhali streams by Stream Tech in 2014. A location map with potential sites is also included in Figure 4-1 [58]. This study considered the potential of Matamuhuri and Sangu for a small scale hydro model with capacity 1 MW and 20 MW respectively. The energy model of these models was done following method 1 to make the technical evaluation simple and convenient due to the lack of detail hydrological data of each site.

The turbine is another major part of designing a hydropower project which typically varies based on the head or relative potential energy, flow rate, and the capacity of the project. Based on the average head and flowrate of Matamuhuri J17 location, the Pelton turbine type mostly suites for 1 MW project due to the lower flow rate and medium head. This type of turbine has the best performance with water having high pressure and low flowrate. However, the Sangu J39 site has a higher flow rate and medium head, which would be suitable for Francis or Kaplan type of turbine. Francis is the most widely used hydro turbine with the highest efficiency with high flowrate, whereas Kaplan is also quite similar to Francis in terms of the design platform. Kaplan turbines work best with high flowrate and low head. However, for the 20 MW hydro projects, Kaplan turbine was assumed to have high performance as the hydro projects are considered as run-of-river or canal based. Francis turbines are preferable for dam based projects [1,58-59]. The capacity factor is presumed as 40% for both models [17]. The electricity export rate is $70/MWh [6].

3.3.4.2 ***Cost Analysis***

Based on the SREDA investment plan, an economic analysis was carried out for two potential sites of Sangu and Matamuhuri to understand the economic feasibility, which can accelerate the process of investment and planning on these projects. Capital cost for 1 MW hydropower project was considered $6.08 million, as estimated for the Matamuhuri J17 site. Fixed O&M cost was assumed $111,000/year for this project. For the 20 MW model, the capital cost is presumed as $2.09 million/MW for Sangu J39 site. The fixed O&M cost for this project is $57,000/MW.year [17]. This study considered debt ratio as 70%, debt interest rate 9.70%, and debt term as 10 years for both models [46]. Project life is presumed as 30 years for both models [17]. Effective income tax is 25% and 100% tax holiday is currently allowed for 5 years for renewable projects in Bangladesh [52].

3.3.4.3 ***GHG Analysis***

In this analysis, only GHG emission generated from transmission and distribution was calculated for the base case and the proposed case of hydropower model and the outcomes were compared to find the emission reduction due to this clean technology. The current fuel mix contributing to the total electricity generation is considered a base case. T&D loss is currently 12% in Bangladesh [6]. GHG credit transaction fee is 2% [54].

3.3.4.4 ***Sensitivity and Risk Analysis***

Sensitivity analysis was performed on after-tax IRR equity considering a sensitivity range of 20% and a threshold value of 15%. Due to a ±20% change in fuel cost of the base case or proposed case or debt interest rate with the same percentage of changes of initial cost, output changes of after-tax IRR equity was calculated and represented in percentage.

3.4 Input Parameter with RETScreen Models

Table 3-2: Energy Model datasheet with input parameters [6, 26,44-46,57- 59, 60]

Model Name	Power from Biomass Model	Solar PV Model	Wind Power Model	Hydro Modl
Project Type	Gas turbine Combined cycle, Gas turbine single cycle, Steam turbine	Photovoltaic	Wind Turbine	Run of river
Key Design Parameter	Fuel Rate: $20/ton Heat rate: 13648 Btu/kWh	Photovoltaic type: mono-Si Efficiency: 15 %	Wind Speed-annual: 4.2 m/s Measured at: 60 m	Hydro Turbine- Matamuhuri- 1 MW -Pelton, Sangu- 20 MW-Kaplan
Power Capacity, kW	1086, 2000, 5044	250000, 5	1000, 5000, 51000	1000, 20000
Availability/ Capacity factor	85%	20%	60%	40%
Electricity Export Rate, $/MWh	70	70	70	70

Table 3-3: Cost Analysis with input parameters [17,49]

Model Name	Power from Biomass Model (Gas Turbine)	Solar PV Model	Wind Power Model	Hydro Model
Initial cost, $/ kW	3200~3600	3500~4000	2100~2200	2000~6000
Fixed O&M cost, $/kW.year	48~81	12.5	20	57~111
Variable O&M cost, $/kW[a] or, $/MWh[b]	4-8[a]	0	8[b]	0

* $/kW[a] = $/kW and $/MWh[b] = $/MWh

3.4.1 GHG Emission Input Parameters

There are three analysis methods for emission analysis in RETScreen, namely Method 1, Method 2, and Method 3.

Table 3-4: Input parameters of GHG emission analysis [6].

Fuel type	Fuel mix, %	Electricity generation efficiency, %	T&D Losses
Natural gas	57.37%	35%	Transmission and Distribution Loss: 12%
Furnace Oil	25.16%	30%	
High Speed Diesel	7.23%	30%	
Coal	2.76%	28%	
Hydro	1.21%	40%	
Solar	0.16%	20%	
Imported electricity	6.12%	100%	

Method 1 is easy, convenient, and very less data is required to make the analysis. Only base case fuel type, region, T&D losses, and GHG credit transaction fees if available are needed for this analysis. Method 2 has options for user-specific data to make a more detailed analysis. Additionally, users can use the fuel mix in percentage to make the baseline analysis more relevant. Electricity generation efficiency for each fuel type is also needed for this analysis. However, Method 3 is used for more detailed analysis with user-specific data. Additionally, the user can insert the global warming potential of methane and nitrous oxide in this method. Carbon dioxide, methane, and nitrous oxide emission factor for the base case can also be specified.

3.4.2 Financial Analysis with Input Parameters

Table 3-5: Input parameters for Financial analysis [46,49,52,61-62]

Model Name	Biomass Model	Solar PV Model	Wind Power Model	Hydro Model
Fuel Escalation rate	5.5%	5.5%	5.5%	5.5%
Inflation rate	5.5%	5.5%	5.5%	5.5%
Project life	20~30 yr	20 yr	20 yr	30 yr
Debt ratio	70%	70%	70%	70%
Debt Interest rate	10.2%	10.2%	9.70%	9.70%
Debt term	10 yr	10 yr	10 yr	10 yr
Effective income tax	25%	25%	25%	25%
Loss carry forward	Yes	Yes	Yes	Yes
Depreciation Method	Straight line	Straight line	Straight line	Straight line
Depreciation period	30	20	20	30
Electricity export escalation rate	5.5%	5.5%	5.5%	5.5%
Tax Holiday	5 years	5 years	5 years	3 years

In this analysis, important financial key parameters are inserted based on the most recent data. According to the most recent data, the inflation rate, discount rate, project life, debt ratio, debt interest rate, effective income tax rate, and depreciation rate are added in the financial analysis worksheet. From this data, each model measures important financial indicators, for instance, pre-tax IRR equity, after-tax IRR equity, simple payback, NPV, Benefit-Cost (B-C) ratio, GHG reduction cost, and so on.

3.4.3 Input parameters for Sensitivity and Risk analysis

Sensitivity and risk analysis offer the user a platform to analyze the sensitivity and risk factor of the financial indicators on input parameters. This analysis is performed on all models using the following input values.

Table 3-6: Input parameters for sensitivity and risk analysis [40]

Sensitivity Analysis				
Model Name	Hydro Model	Solar PV Model	Power from Biomass Model	Wind Power Model
Analysis performed on	After tax IRR equity	After tax IRR equity	After tax IRR equity	After tax IRR equity
Sensitivity Range, %	20	20	20	20
Threshold, %	15	15	15	15
Risk Analysis				
Analysis performed on	NPV	NPV	NPV	NPV
Range of Initial Cost, %	20	20	20	20
Range of O&M, %	20	20	20	20
Range of electricity export rate, %	20	20	20	20
Range of Debt ratio, %	20	20	20	20
Range of debt interest rate, %	20	20	20	20
Range of Debt term, %	20	20	20	20
Level of risk, %	10	10	10	10

4. RESULTS AND DISCUSSION

4.1 Introduction

Power generation from several clean energy sources has been modelled using RETScreen In this chapter, these models were discussed and critically assessed in terms of technical features, financial feasibility, economic viability, and risk and sensitivity of the project in the context of Bangladesh. The discussion presented in this chapter contains technical evaluation, economic evaluation, environmental assessment and sensitivity and risk analysis for each of the models.

RETScreen models for biomass, solar, wind, and hydro were designed with technical details. In addition, parameters were set based on design value, or literature. The economic evaluation was performed based on model wise Capital Expenditure (CAPEX) for the predefined capacity, fixed cost, and variable operating cost from module wise literature and typical percentages of Fixed-Capital Investment (FCI) values. To evaluate the greenhouse gas emission, the emission rate of the proposed technology was compared with conventional technology. RETScreen software evaluated sensitivity based on a given sensitivity range. It also measured the project risk by comparing the outputs in each range of the input parameter values of the models.

Several possible models were evaluated to understand the feasibility and find the most attractive and profitable option for potential resources of Bangladesh. For each case, multiple fuel options, several capacity parameters, and different possible technology for power generation were considered. Meteorological data from different online weather databases were previously integrated and incorporated into RETScreen software, which was helpful to design RETScreen models. Especially monthly solar radiation, average temperature, relative humidity, wind speed data were useful for solar PV and wind models. Project analysis for each model can be found briefly in the following sections.

4.2 Technical Evaluation

4.2.1 Biomass Model

A thorough study had been done to understand the technical features related to potential sources in Bangladesh and assess the technical feasibility of RETScreen models. Renewable energy models in RETScreen were compared in terms of technical features, for instance, rate of energy production, efficiency, capacity factor, alternative technology, and fuel selection.

Several RETScreen models were prepared with different technology to generate electricity from biomass using gas turbine, steam turbine, and gas turbine combined cycle. RETScreen energy model calculates electricity delivered to the grid considering miscellaneous loss. Single-cycle gas turbine biomass energy model with a capacity of 1MW calculated 8086 MWh electricity generation that can be delivered to the grid, steam turbine-based model calculated 7828 MWh electricity. However, the gas turbine combined cycle model measured 9022 MWh electricity supply to the grid. The summary of output parameters can also be found in Table 4-1.

For both multifuel cases, electricity delivered to the grid is 9346 MWh, which is larger than the single fuel option. To figure out the most feasible option between the three models, the economic feasibility of multiple fuel facility is required.

Table 4-1: Output parameters of the energy model of 1 MW Gas turbine combined cycle of biomass option.

Key Output Parameters	
Steam turbine Power Capacity, kW	179
Total Power Capacity, kW	1265
Fuel Required, GJ/h	15.6
Heating Capacity, kW	1830
Electricity Exported to Grid, MWh	9416

4.2.2 Solar PV Model

From product database capacity of 250,000 kW and 5 kW was chosen for two models which also included manufacturer, model, capacity per unit, and a number of units. The summary of input and output parameters is specified in Table 4-2.

For a small scale off-grid model, the base case power system was accounted as power generation from diesel, as it is mostly used in isolated areas to support household power demand. The heat rate of diesel is 10500 Btu/kWh [63]. Daily load for both base case and proposed case are calculated as 8 kWh assuming 14 h operation per day [64]. Inverter with capacity 5 kW was designed for this model with 90% efficiency. The battery was sized considering three days of autonomy, which means, it can operate continuously three days without charging to support blackout days. During rainy days or days having lower irradiance, the battery can support without external power or electricity generator. For three days of autonomy, or backup in the case of unavailability of solar power, battery is designed for 24 kWh, having voltage 48V and capacity 500 Ah with lithium-ion battery [64]. Maximum depth of discharge for lithium-ion battery is 80% [65] with charger controller efficiency 95% [66].

Table 4-2: Output parameters of the energy model of solar PV model with capacity 250 MW

Output Parameters	
Average daily solar radiation- horizontal, kWh/m^2.day	4.99
Average daily solar radiation- tilted, kWh/m^2.day	5.46
Annual electricity exported to the grid, MWh	360390
Capacity factor, %	16.4

Instead of having some common parameters, the entire technical features of the grid-connected model and off-grid model are significantly different. The industrial-scale 250 MW solar PV RETScreen model calculated 360,390 MWh electricity exported to the grid in a year and capacity factor 16.4%. Solar PV model with capacity 5 kW measured annually 3.39 MWh electricity exported to load with capacity factor 14.4%. This technical evaluation is made considering relevant parameters from the literature and the current situation of Bangladesh.

4.2.3 Wind Model

The scope of wind resource in Bangladesh has been greatly explored through wind mapping covering all potential sites [26]. Based on this data, three RETScreen models were designed with capacity 1 MW, 5 MW, and 50 MW. Although, electricity generation from wind power is one of the most expensive technologies due to low capacity factor and high installation cost, the government of Bangladesh has planned to explore all renewable potentials inside the country and targeted 10% of total electricity generation from renewable resources by 2021 [1].

RETScreen model calculated annual electricity exported to grid-based on input parameters. This value is found 492 MWh for 1 MW wind power model, 2,458 MWh for 5 MW model, and 24,583 MWh for 50 MW model. Capacity factor is 5.6% for 1 MW, 5 MW, and 50 MW model.

Wind potential is largely understood by wind power classification which is usually done based on location-specific wind speed and wind power density. All nine locations inside Bangladesh had been classified as wind power class 1, which means comparatively lower wind speed (less than 5.6 m/s) and wind power density (less than 200 W/m^2) at measuring height of 50 m [26,57]. The capacity of potential wind power is also determined based on this classification. Eventually, it can be interpreted that small-scale or micro-scale wind projects might be feasible based on the available wind data. Large scale wind power projects can be planned at a higher elevation more than 100 meters which are yet to be explored in Bangladesh.

4.2.4 Hydro Model

Due to the continuous depletion of fossil fuel, the government of Bangladesh is focusing on diversifying sources of power generation to secure its economy in the long term. Geographically Bangladesh is situated in the lower part of the delta, having lots of water bodies that emerge with hydropower potential. Although lower elevation, high population density, and lack of hydrological data make the hydro project very difficult to implement. According to the SREDA investment plan, Bangladesh has around 60 MW of hydropower potential in several sites [17]. A map including hydrological data is added in Figure 4-1. In this section, two hydro models with a capacity of 1 MW and 20 MW are designed with RETScreen software.

Both models are designed to export electricity to central grid. RETScreen model calculated electricity exported to grid as 3504 MWh for 1 MW hydropower plant and 70,080 MWh for 20 MW plant.

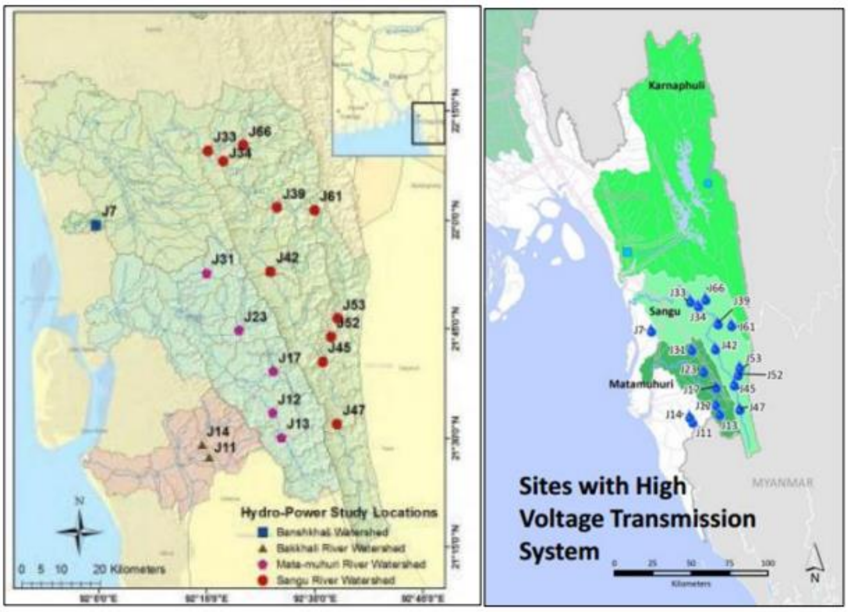


Figure 4-1: Map of potential sites for small scale hydropower project in Chittagong [58]

More technical features for hydro projects could be explored from RETScreen software if site-wise more accurate hydrological data were available. As Bangladesh is a highly populated country, there are socio-economic factors involved in hydro projects which also need to be considered during the resource assessment. Due to the lack of appropriate data, investment, or funding is not considered yet to initiate the project. Finally, to explore the identified potential and utilize it for electricity generation, detailed resource assessment is inevitable.

4.3 Economical Evaluation

4.3.1 Biomass Model

In this section, a financial analysis was performed considering major costs to understand the overall cost and outcome, which can serve means to understand its feasibility for potential clean energy models. It is an ineluctable part of a project for the investor, planner, or decision-maker to decide to go/no go for this project or to screen out financially unattractive projects. With RETScreen software, economic evaluation can be made to compare conventional and unconventional energy projects and more specifically estimate the amount of energy saved or portray the project cost. It also helps to understand high-quality pre-feasibility and feasibility study which are critical to making the right decision for a project. Accuracy of projected cost varies in a range of ± (40-50) % in the pre-feasibility stage and ± (15-25)% in the feasibility stage [40].

RETScreen model calculated several financial indicators based on the inserted cost information, for example, Internal Rate of Return (IRR), simple payback, equity payback, Net Positive Value (NPV), annual life cycle savings, Benefit-Cost (B-C) ratio, energy production cost and GHG reduction cost considering project life 30 years for all biomass models. These indicators facilitate the process of the economic evaluation of the project. For gas turbine combined cycle with a capacity of 1.086 MW, after-tax IRR equity was found negative, simple payback more than 24 years, NPV value as -$8.26 million, B-C ratio -7.44, energy production cost $98.42/MWh and GHG reduction cost $99/ton CO_2 from RETScreen model. A biomass power plant with a single cycle gas turbine can also be an alternative option. RETScreen model calculated after-tax IRR equity negative, simple payback -15.9 years, NPV -11.62 million, B-C ratio -9.75, energy production cost $116.1/MWh and GHG reduction cost $161/ton CO_2. RETScreen model calculated fuel costs $695,355/yr for gas turbine combined cycle and gas turbine single cycle, and $2,206,373/yr for steam turbine model. Steam turbine-based biomass power plant shows negative results in financial indicators.

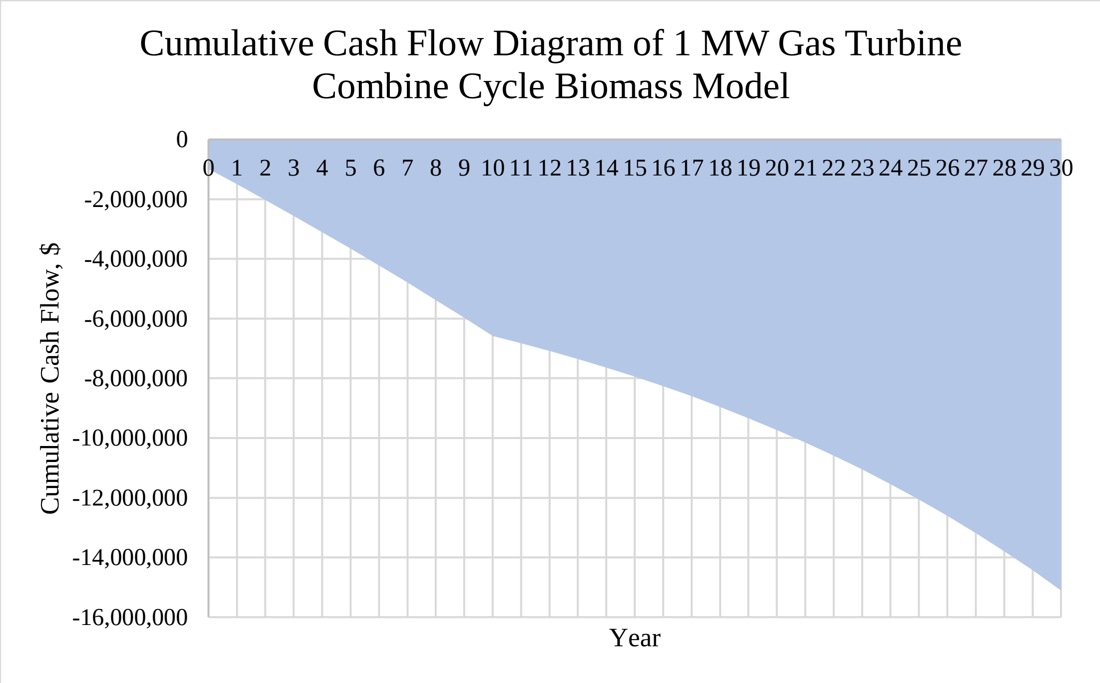


Figure 4-2: Cumulative cash flow diagram of Gas turbine combined cycle biomass power project having capacity of 1 MW.

The economic viability of multiple fuel options with a gas turbine-combined cycle was also checked for RETScreen models. Financial indicator for both 50-50 biomass-diesel and 75-25 biomass-diesel option showed negative output values. It clearly showed multiple fuel options with predefined fuel percentages with diesel are not economically viable due to the high fuel cost of diesel. Fuel cost for 50-50 biomass-diesel option was found $1.14 million/yr, whereas 75-25 biomass-diesel costs $1 million/yr, relatively more expensive than the annual income from electricity export with current electricity export rate.

A cumulative cash flow diagram with a breakeven point for each model was found in the financial summary part of RETScreen models, also shown in Figure 4-2 for 1 MW Gas Turbine Combined Cycle biomass model. Cumulative cash flow diagram for all other models are included from Figure A-1 to Figure A-51.

4.3.2 Solar PV Model

In this section, cost analysis and financial analysis had been done to evaluate the economic viability of solar PV models considering the major cost. From this analysis, overall cost and outcome can be measured and the outcomes can be compared with the base case to understand the feasibility of this project before going implementation.

Based on the input parameters, the RETScreen model calculated total cost, savings, income, and important financial indicators. For the industrial scale 250 MW model, this software measured total initial cost as $375 million and total annual savings from electricity export as $25 million. After-tax IRR equity was estimated as 4.5%, simple payback 17.2 yr, NPV -$13.97 million, B-C ratio 0.88, energy production cost $72.29/MWh and GHG reduction cost $5/ton CO_2.

For a small-sized 5 kW solar PV model, the total initial cost is $10,073, and the annual savings comparing the base case is $1,435. RETScreen also calculated after-tax IRR equity 22%, simple payback 7.4%, NPV $12,592, B-C ratio 5.17 and GHG reduction cost $456/ton CO_2.

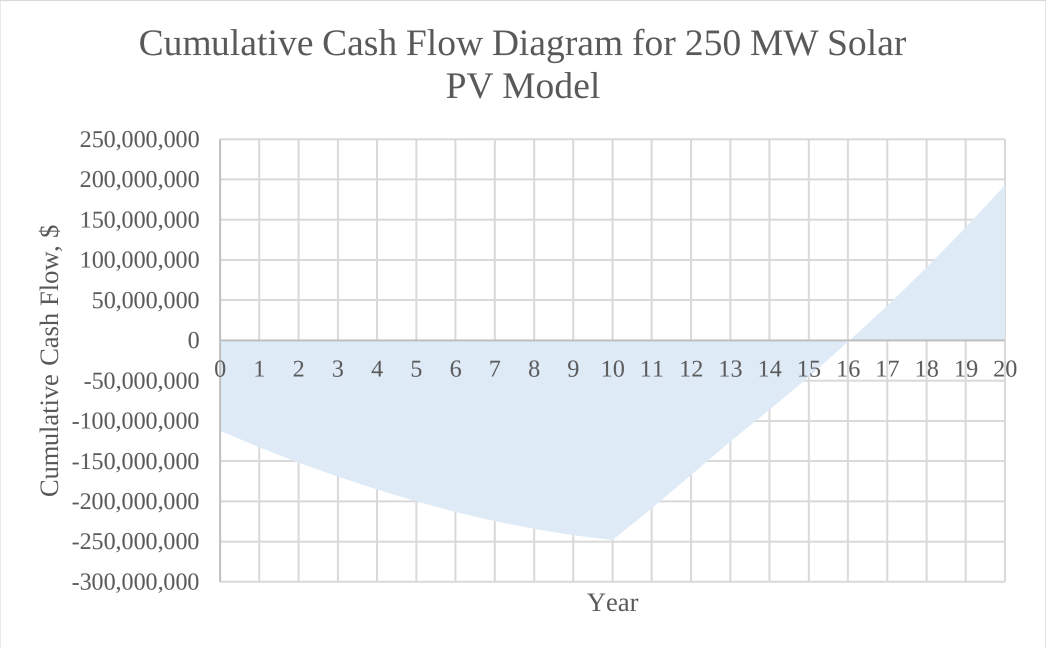


Figure 4-3: Cumulative cash flow diagram for Solar PV model with capacity 250 MW

Cumulative cash flow diagram containing yearly cumulative cash flows and break-even point for each model was provided in the financial analysis worksheet by RETScreen software. Figure 4-3 shows this diagram for the solar PV model with the capacity of 250 MW. Cumulative cash flow diagram for 5 kW Solar PV model is added in Figure A-53.

From this analysis, it is elucidated that due to high capital cost and low-capacity factor or low solar to electricity generation efficiency, solar PV models are not economically very attractive option for industrial scale compared to other technologies. Small scale off-grid option is economically feasible. However, no fuel cost and abundant solar potential in Bangladesh make this technology a worthwhile opportunity to utilize the potential and make the power planning more secure. Moreover, incentives or grants or income tax exemption from the government can help the investors to encourage more projects on this technology.

4.3.3 Wind Model

Financial viability has been explored for wind models with capacity 1 MW, 5 MW, and 50 MW through RETScreen software.

RETScreen financial analysis worksheet is a template that consists of a set of functions that can easily calculate the financial indicators. For the 5 MW model, this software calculated total initial cost as $7.59 million, annual savings, and income as $172,079. This model also measured after-tax IRR-equity as -15.1%, simple payback 115 years, NPV -$7.48 million, B-C ratio -2.29, energy production cost $227/MWh and GHG reduction cost $407/ton CO_2.

For the 1 MW model, the total initial cost was $1.5 million and total annual saving or income as $34,416. This model also calculated after-tax IRR-equity -15.1%, simple payback 115 years, NPV -$1.5 million, B-C ratio -2.29, energy production cost $227/MWh and GHG reduction cost $408/ton CO_2.

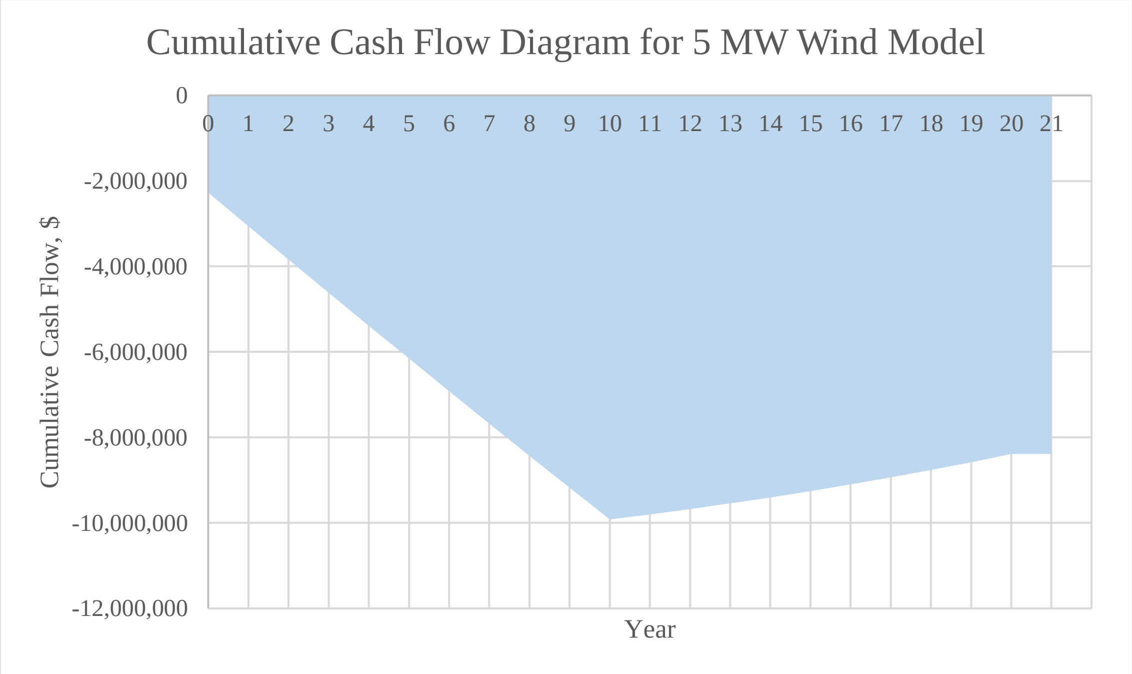


Figure 4-4: Cumulative cash flow diagram of wind model with capacity 5 MW

The total initial cost was estimated as $75 million whereas annual savings or income was found $1.72 million for 50 MW model. This model also estimated after-tax IRR-equity as -15%, simple payback as 114 years, NPV as -$73 million, B-C ratio as -2.28, energy production cost as $225/MWh and GHG reduction cost as $401/ton CO_2. The cumulative cash flow diagram was also portrayed in each RETScreen model in the financial analysis section, also shown in Figure 4-4 for 5 MW wind model. For 1 MW and 50 MW wind model, this diagram is included in Figure A-55 and Figure A-57.

All financial indicators indicated that wind projects are not financially feasible due to high initial cost, low electricity export rate, and low-capacity factor. Wind power option is one of the most expensive renewable technologies compared to other conventional technologies. It was also checked by trial and error that if the electricity export rate is $370/MWh or more, then the project might become economically attractive. However, incentives, grants, or tax exemption can also be another medium to encourage this project.

4.3.4 Hydro Model

In this section, economic evaluation is performed by inserting cost parameters and important financial inputs. This analysis is done in cost analysis and financial analysis worksheet by measuring financial indicators through a set of inbuilt calculations in the worksheets.

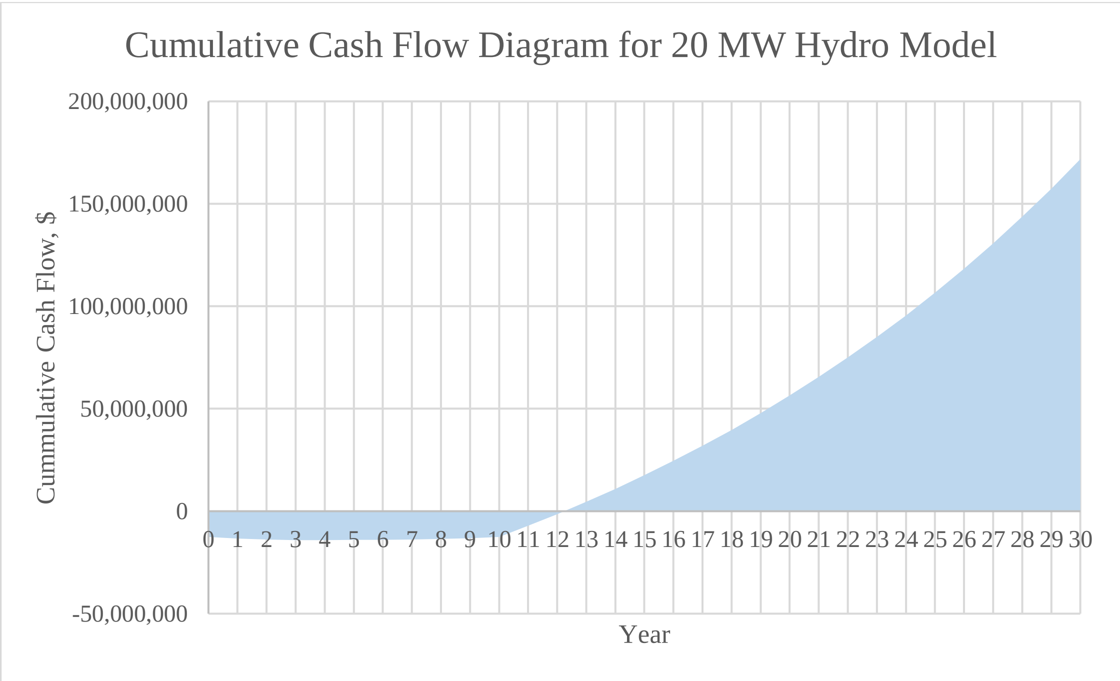


Figure 4-5: Cumulative cash flow diagram of 20 MW hydropower project.

The total initial cost for the 1 MW hydro model was $6.08 million and annual savings and income $245,280. This model estimated after-tax IRR equity 0.9%, simple payback 45.3 years, NPV -$2.86 million, B-C ratio -0.57, energy production cost $101/MWh and GHG reduction cost $88/ton CO_2. For the 20 MW hydro model, the total initial cost was calculated $41.8 million, and annual savings and income $4.9 million. It also estimated after-tax IRR equity 14%, simple payback 11 years, NPV $51.9 million, B-C ratio 5.14, energy production cost $40/MWh and GHG reduction cost $80/ton CO_2.

A cumulative cash flow diagram is represented in the financial analysis worksheet of each model, also shown in Figure 4-5 for 20 MW hydro model. For 1 MW hydro model, this figure is added in Figure A-59. From this analysis, it is comprehensible that, hydropower project of 20 MW in the Sangu J39 site is economically viable due to adequate hydro potential at that site and moderate initial cost. However, 1 MW hydro model in the Matamuhuri J17 site might not be economically feasible due to higher capital cost and comparatively less hydro potential for power generation. The study only considered the available data for these aforementioned sites. There are scopes to explore more on these sites which require rigorous study and resource assessment for these projects.

4.4 Environmental Assessment

4.4.1 Biomass Model

Global warming and Greenhouse Gas (GHG) emission due to increasing industrialization raises interest in environmental awareness and attention towards renewable energy technologies. Major GHGs attributed to carbon dioxide, methane, and nitrous oxide. With RETScreen software, GHG emission reduction was estimated associated with clean energy technology instead of using conventional technologies. It helps the planner to understand the GHG reduction potential of the proposed project.

Table 4-3:Important parameters of emission analysis of biomass models

GHG Emission Summary	CO_2 emission factor, kg/GJ	CH_4 emission factor, kg/GJ	N_2O emission factor, kg/GJ	GHG emission factor for electricity export, ton CO_2/MWh	GHG Emission, ton CO_2	GHG Emission Reduction, ton CO_2
Gas Turbine Combined Cycle 1 MW						
Base Case	191.9	0.0116	0.0043	0.697	6,560	-
1 MW Gas turbine combined cycle	0	0.0299	0.0037	0.697	1,004	5,556
Gas Turbine Combined Cycle 2 MW						
Base Case	191.9	0.0116	0.0043	0.697	12,100	-
2 MW Gas turbine combined cycle	0	0.0299	0.0037	0.697	1,834	10,266
Gas Turbine Combined Cycle 5 MW						
Base Case	191.9	0.0116	0.0043	0.697	30,669	-
5 MW Gas turbine combined cycle	0	0.0299	0.0037	0.697	4,666	26,002
Gas Turbine Single Cycle 1 MW						
Base Case	194	0.0115	0.0044	0.703	5,685	-
1 MW Gas turbine single cycle	0	0.0299	0.0037	0.703	899	4786

GHG Emission Summary	CO_2 emission factor, kg/GJ	CH_4 emission factor, kg/GJ	N_2O emission factor, kg/GJ	GHG emission factor for electricity export, ton CO_2/MWh	GHG Emission, ton CO_2	GHG Emission Reduction, ton CO_2
Gas Turbine Sigle Cycle 2 MW						
Base Case	191.9	0.0116	0.0043	0.697	10,495	-
2 MW Gas turbine single cycle	0	0.0299	0.0037	0.697	1,663	8832
Gas Turbine Sigle Cycle 5 MW						
Base Case	191.9	0.0116	0.0043	0.697	27,080	-
5 MW Gas turbine single cycle	0	0.0299	0.0037	0.697	4,290	22,790
Steam Turbine 1 MW						
Base Case	191.9	0.0116	0.0043	0.697	5,454	-
1 MW Steam turbine	0	0.0299	0.0037	0.697	1,342	4,113
Steam Turbine 2 MW						
Base Case	191.9	0.0116	0.0043	0.697	12,052	-
2 MW Steam turbine	0	0.0299	0.0037	0.697	3,271	8,780
Steam Turbine 5 MW						
Base Case	191.9	0.0116	0.0043	0.697	25,585	-
5 MW Steam turbine	0	0.0299	0.0037	0.697	6,727	18,858

With fuel mix data and greenhouse gas emission factor, RETScreen software measured GHG emission factor for the base case as 0.697 ton CO_2/MWh and GHG emission of 6,560 ton equivalent CO_2 for gas turbine combined cycle. For the proposed case, the GHG emission factor was found the same as the base case and GHG emission was 1004 ton CO_2, which resulted in 5,556 tons of equivalent CO_2 reduction comparing base case technology. This value is similar to 997 cars and light trucks off the road. A summary of the important parameters is delineated in Table 4-3.

However, for gas turbine single cycle, the GHG emission factor was found as 0.703 ton CO_2/MWh for both base case and proposed case. Total GHG emission was calculated as 5,684 ton CO_2 for the base case and 899 ton CO_2 for the proposed case. The model also measured 4,786 ton CO_2 emission reduction comparing base case which was equivalent to 859 cars and light trucks off the road.

This analysis helped to evaluate the environmental feasibility of potential biomass power projects in Bangladesh. Based on this analysis, both gas turbine single cycle and combined cycle biomass power projects were found environmentally feasible.

4.4.2 Solar PV Model

An environmental assessment was carried out by measuring the emission of important greenhouse gas, carbon dioxide, methane, and nitrous oxide, for instance, and finding GHG emission savings by comparing it with base case emission.

From the 250 MW solar PV model, the GHG emission factor is found 0.697 ton CO_2/MWh and total emission 251,092 ton CO_2 for the base case. From the proposed case, the GHG emission factor is the same and the total emission is 30,131 ton CO_2/MWh. This results in 220,961 tons of equivalent CO_2 reduction or 39,660 cars and light trucks not used. In this analysis, the GHG emission factor for power generation from solar is considered zero, this aforementioned emission from the proposed case is coming from transmission and distribution which originates from the manufacture of metal, power lines, substation, power transmission, and disposal of lines or substations [67]. A summary of the important parameters is represented in Table 4-4.

From the 5 kW solar PV model, the GHG emission factor was found 0.252 ton CO_2/ MWh and total emission was 2.3 ton equivalent CO_2 for the base case. This model calculated 0 ton CO_2/ MWh and total emission 0 ton CO_2 for the proposed case, which resulted in 2.3 ton savings of CO_2 from this project.

Table 4-4: Important parameters of emission analysis of solar PV models

GHG Emission Summary	CO_2 emission factor, kg/GJ	CH_4 emission factor, kg/GJ	N_2O emission factor, kg/GJ	GHG emission factor for electricity export, ton CO_2/MWh	GHG Emission, ton CO_2	GHG Emission Reduction
Solar PV Model 250 MW						
Base Case	191.9	0.0116	0.0043	0.697	251,092	-
250 MW Solar PV project	0	0	0	0.697	30,131	220,961

Solar PV Model 5 kW						
Base Case	69.3	0.0019	0.0019	0	2.3	-
5 kW Solar PV	0	0	0	0	0	2.3

This analysis identified the emission potential and compared it with baseline technology to understand the potential savings of emission. Additionally, it also showed the amount of GHG emission reduction in tons of equivalent CO_2 and other common units. Both models were found environmentally feasible from this analysis. Undoubtedly, this technology is environmentally more benign than other conventional technologies due to less GHG emission potential.

4.4.3 Wind Model

An environmental assessment was done for each model through the emission analysis section of RETScreen software. Through this analysis, the total emission potential of proposed clean technology or the proposed case is measured. This emission potential is then compared with the baseline case or conventional technology to understand the emission reduction scope.

Table 4-5: Important parameters of emission analysis of wind models

GHG Emission Summary	CO_2 emission factor, kg/GJ	CH_4 emission factor, kg/GJ	N_2O emission factor, kg/GJ	GHG emission factor, ton CO_2/MWh	GHG Emission, ton CO_2	GHG Emission Reduction
Wind Model 5MW						
Base Case	191.9	0.0116	0.0043	0.697	1713	-
5 MW Wind Model	0	0	0	0.697	205	1,507
Wind Model 1MW						
Base Case	191.9	0.0116	0.0043	0.697	343	-
1 MW Wind Model	0	0	0	0.697	41	302
Wind Model 50 MW						
Base Case	191.9	0.0116	0.0043	0.697	17,127	-
50 MW Wind Model	0	0	0	0.697	2,055	15,072

For the 5 MW wind model, the GHG emission factor for the base case was considered 0.697 ton CO_2/MWh, and total emission was calculated 1713 tons of CO_2. For the proposed case GHG emission factor is zero for electricity generation, but for transmission and distribution, the GHG emission factor was 0.697, similar to the base case. The total emission for the proposed case was calculated as 205 tons CO_2. This emission also includes the manufacture of metal, power lines, substation, power transmission, and disposal of lines or substations [67]. This wind model accounted for GHG emission savings of 1507 ton equivalent CO_2. A summary of important parameters is depicted in Table 4-5.

1 MW wind model considered the GHG emission factor as 0.697 ton equivalent CO_2/MWh and estimated total emission 342.5 ton equivalent CO_2 for the base case. For the proposed case GHG emission factor is the same as the base case and total emission is 41 ton equivalent CO_2. This proposed clean technology can save 301 ton CO_2 compared to the base case.

A similar method was also followed for the environmental evaluation of the 50 MW wind model. GHG emission factor for base case was 0.697 ton equivalent CO_2/MWh, same as other models. Total emission was found 17,127 ton CO_2 for the current fuel ratio for total power generation or base case. GHG emission factor for the proposed case was considered the same as the base case and total emission was calculated as 2,055 ton equivalent CO_2. This proposed wind model can save 15,072 ton CO_2.

Undeniably wind technology is environmentally promising than traditional ones due to zero GHG emission during electricity generation. It can be a good option to opt for this technology if the resource potential is worthwhile and economically sustainable for the long term.

4.4.4 Hydro Model

Hydropower plant does not have direct air or water pollution which in turn can be a benign option to reduce GHG emission. Nevertheless, hydro projects can have long term social and environmental impacts due to changes in river flow, water temperature, allocation of land, ecology, and natural habitats especially with dam or reservoir depending on the size of the hydro-generator and geographical location. In addition to that GHG emissions are involved in the installation and dismantling of hydropower plants depending on the capacity and type of the project.

For the 1 MW hydro model, the GHG emission factor was calculated 0.697 ton CO_2/MWh and total emission 2,441 ton CO_2 for the base case. For the proposed case, the GHG emission factor was the same as the base case, and total emission was estimated 293 ton CO_2. This project can save an emission of 2,148 ton equivalent CO_2.

GHG emission factor was considered 0.697 ton CO_2/MWh for both base case and the proposed case for the 20 MW hydro model. This model estimated total emission of 48,826 ton equivalent CO_2 for the base case and 5,859 ton CO_2. This results in savings of 42,967 ton CO_2. Table 4-6 represents key parameters of emission analysis for the hydro model having capacity 20 MW.

As mentioned earlier, although hydro projects can be a compelling option as clean technology to reduce GHG emission, there is a long-term environmental impact that could not be estimated in this study. Before implementing any hydro project, this impact needs to be addressed and reassessed.

Table 4-6: Important parameters of emission analysis of the hydro models

GHG Emission Summary	CO_2 emission factor, kg/GJ	CH_4 emission factor, kg/GJ	N_2O emission factor, kg/GJ	GHG emission factor for electricity export, ton CO_2/MWh	GHG Emission, ton CO_2	GHG Emission Reduction, ton CO_2
Hydro Model 20 MW						
Base Case	191.9	0.0116	0.0043	0.697	48,826	-
20 MW Hydropower plant	0	0	0	0.697	5,859	42,967
Hydro Model 1 MW						
Base Case	191.9	0.0116	0.0043	0.697	2,441	-
20 MW Hydropower plant	0	0	0	0.697	293	2,148

4.4.3 GHG Emission Comparison Based on Technology

A comparison was made based on the GHG emission from all four renewable sources and its associated technologies. Figure 4-6 shows this comparison for all technologies and base case. So, approximately 85% reduction in GHG can be obtained with these technologies. Additionally, solar, wind and hydro had the lowest emission which is only 0.08 ton of CO_2 /MWh. This emission is slightly higher for biomass models. It varies between 0.10~0.16 ton of CO_2/MWh. Undoubtedly, this reduced rate of emission is the most attractive part of these renewable projects.

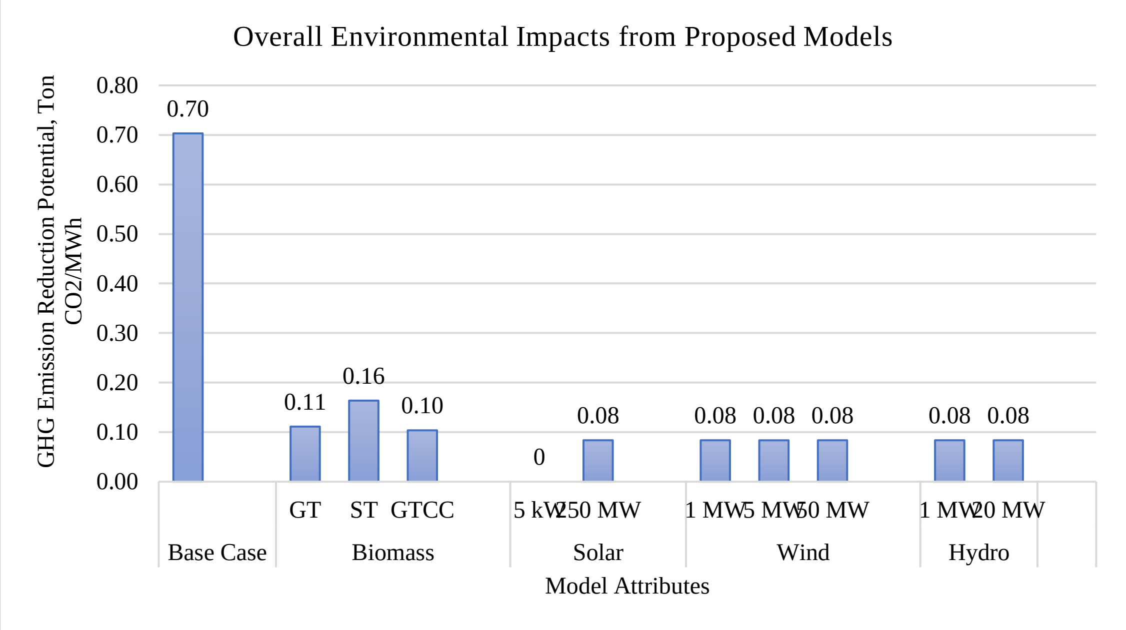


Figure 4-6: Environmental impact from proposal models.

4.5 Sensitivity and Risk Analysis

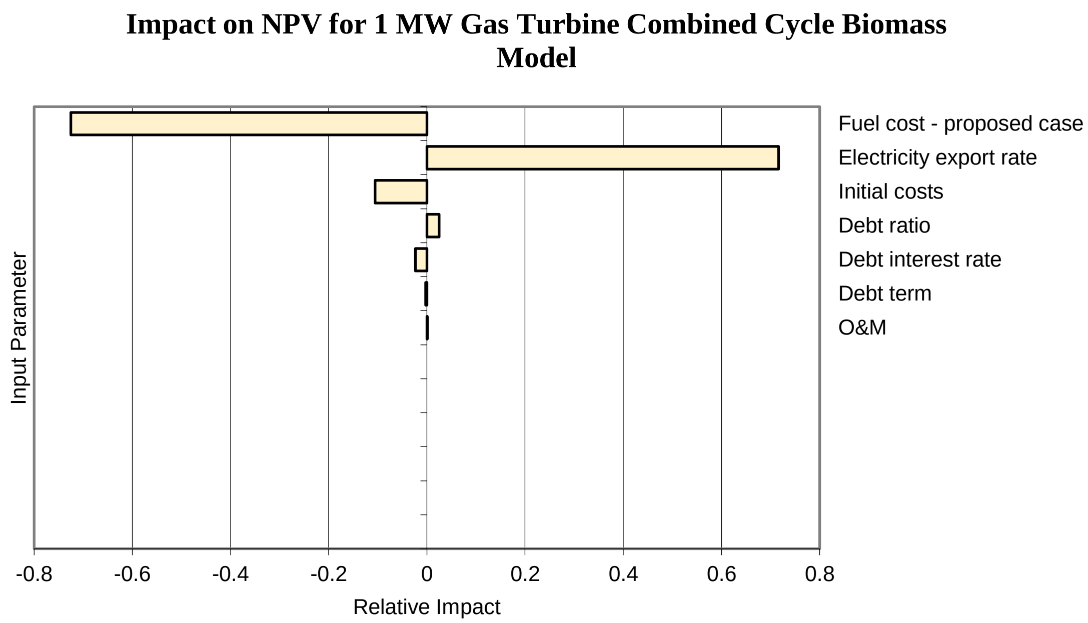
4.5.1 Biomass Model

RETScreen sensitivity and risk analysis section provide an understanding of the sensitivity of important financial indicators associated with technical and financial input parameters. It also provides information about the relationship of input parameters with important financial indicators and manifests the greatest impact on it. In the risk analysis worksheet, there are two sections: Sensitivity Analysis and Risk Analysis. Sensitivity analysis can identify the most important parameters which determine the project viability or vulnerability. Risk analysis provides a ranking of the relative impact of key input parameters that affect the important financial indicators (NPV, IRR, for example) in a positive or negative direction of impact [40].

The risk analysis method is quite complicated compared to the sensitivity analysis. This software uses Monte Carlo simulation for risk analysis of a project. Monte Carlo simulation is a computational technique that estimates uncertainty and impact of risks in a process by drawing probability distribution having inherent uncertainty and several random variables. In this analysis, 500 random values are selected for each input parameter using a normal distribution with a mean of 0 and a standard deviation of 0.33. Each random value is then multiplied by a percentage of the range specified by the user in the risk analysis section, which results in a 500x9 matrix containing 500 financial outcomes [40].

The impact chart of this analysis showed the relative effect of input parameter variation over the financial outcomes, for example, after-tax IRR equity or NPV. Risk analysis for NPV value is performed for gas turbine combined cycle biomass model and gas turbine single cycle. From this analysis, the electricity export rate, initial cost, and fuel cost for the proposed case had the maximum impact on NPV. Similarly, for gas turbine single cycle biomass model also showed the highest impact for these three parameters. The input variable range was considered 20% for this analysis. For a 10% level of risk, the minimum level of confidence was found -$14.64 million, and the maximum value -$8.27 million for gas turbine combined cycle biomass model. It is the 5th percentile and the 95th percentile of the 500 values respectively calculated by Monte Carlo simulation. However, the minimum level of confidence was found -$11.5 million and the maximum value is -$4.8 million for gas turbine single cycle biomass model.

The relationship of key input parameters with the financial outcome can be interpreted with this analysis, which plays an important role in decision making for the planner. It also gave a direction on how much risk could be taken in a project and its impact on the outcome through this analysis. Additionally, it also measured the extent of each impact done by changes in the input parameter, which is represented by the impact graph, as demonstrated in Figure 4-7 for 1 MW Gas Turbine Combined Cycle biomass model. All other impact and distribution curves are included in Figure A-2 to Figure A-52. Based on this analysis, none of the biomass technology is financially attractive.



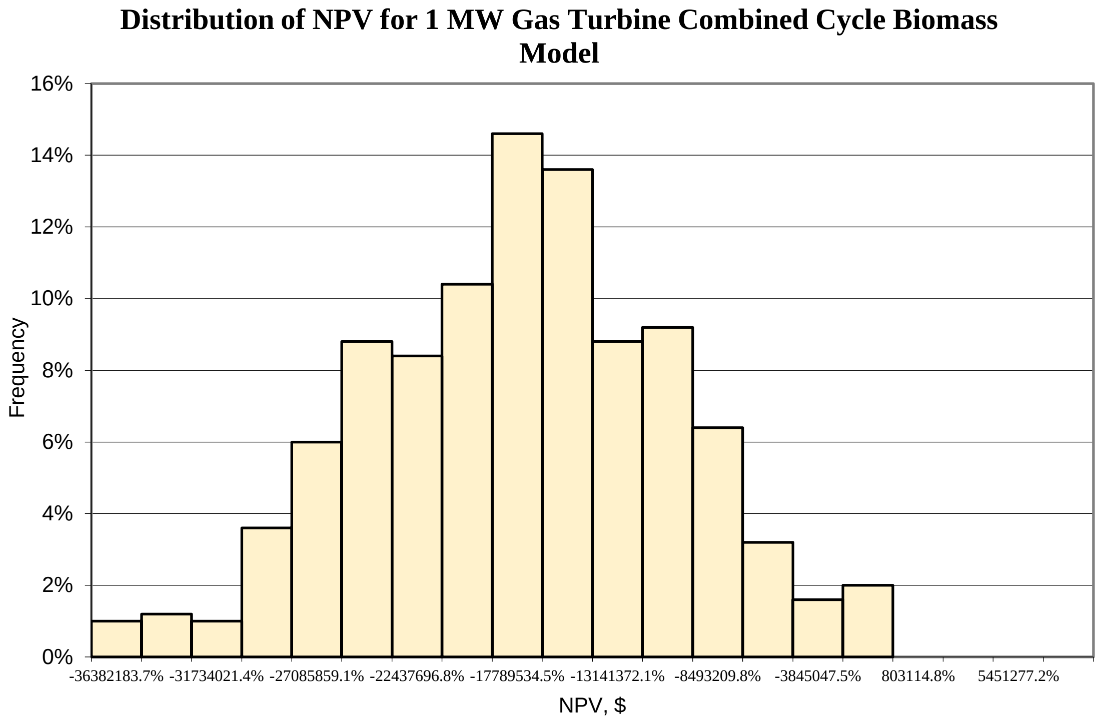


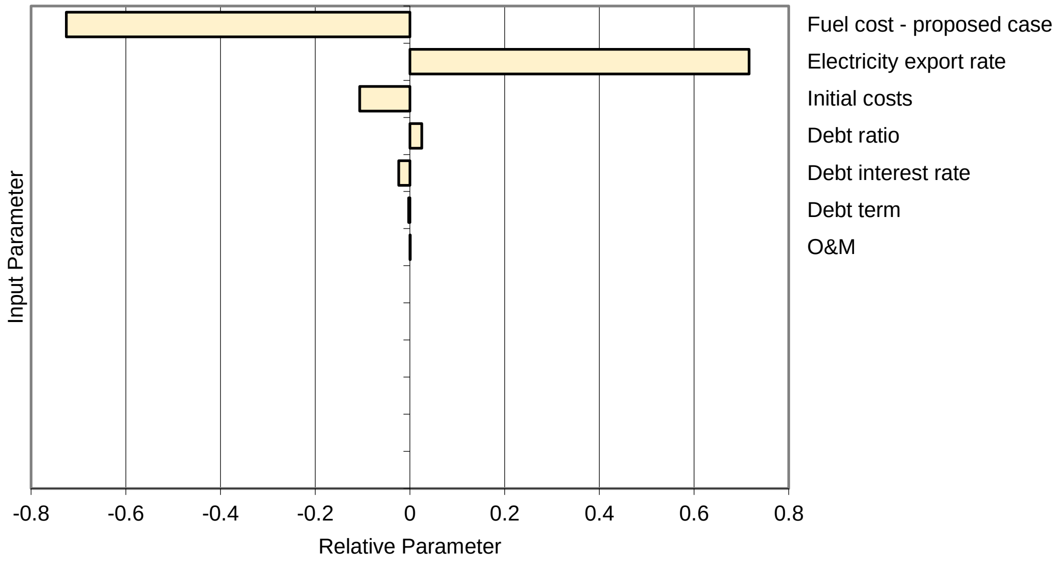
Figure 4-7: Risk Analysis for 1 MW Gas turbine combined cycle biomass model

4.5.2 Solar PV Model

Sensitivity and risk analysis were performed for solar PV models in RETScreen software. This analysis facilitated an understanding of important parameters and their impact factor on the financial indicators of the project.

For the 250 MW solar PV model, the output value of after-tax IRR equity varied around (1.4~8.9) % which is below the threshold limit of 15%. It means the project is not financially attractive. For the 5 kW solar PV model, this output value changed within a range of (11~32) %. It shows that the project is financially feasible if the other values remain as predicted.

Impact on NPV for 250 MW Solar PV Model



Distribution of NPV for 250 MW Solar PV Model

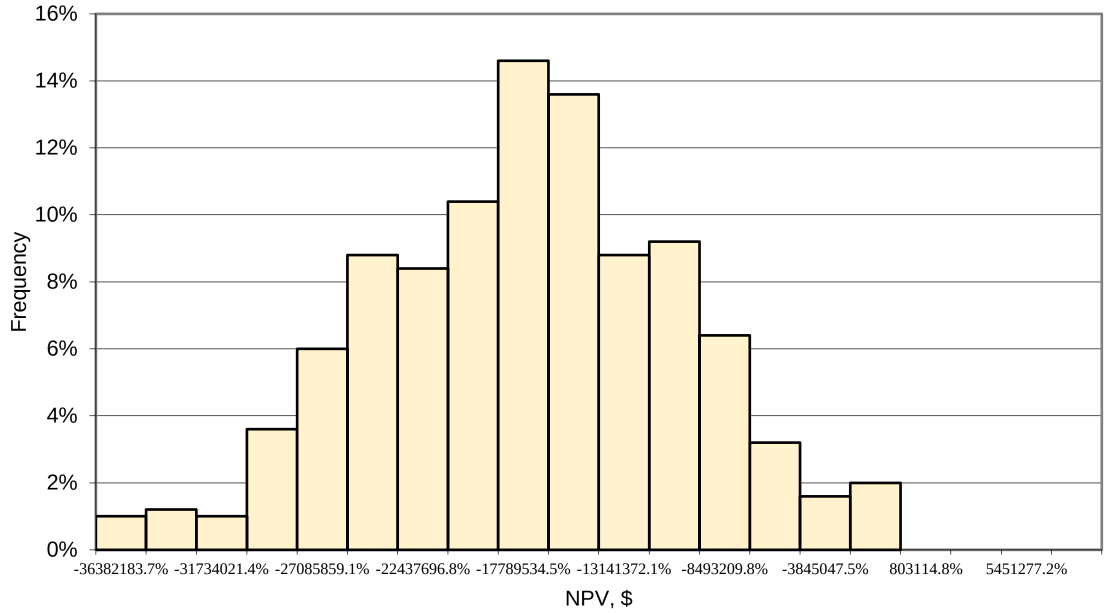


Figure 4-8: Sensitivity analysis of 250 MW solar PV model

Risk analysis was carried out on NPV of both models considering a 20% change in values of initial cost, O&M, electricity export rate, debt ratio, debt interest rate, and debt term. The relative impact of each input parameter on NPV is obtained by standard multiple linear regression and the output is represented graphically in risk analysis worksheet. For this analysis, 500 random input values are generated using a normal distribution with a mean of 0 and a standard deviation of 0.33. 500 output values are obtained by multiplying input parameters with the percentage of change of 20%.

For the 250 MW solar PV model, electricity export rate, initial costs, and debt interest rate had the highest impact factors, and the median value was $185 million among 500 output values of NPV. Assuming a 10% level of risk, minimum and maximum level of confidence are found as -$70 million and $64 million. Figure 4-8 depicts the impact graph and probability histogram of this analysis for 250 MW Solar PV model. For the 5 kW solar PV model, the fuel cost of the base case, initial cost, and debt interest rate had relatively most impacts on NPV, and the median value was $12,896. Similarly, for a 10% level of risk, the maximum and the minimum level of confidence were found $15,863 and $10,148. Impact and distribution curve for 5 kW Solar PV model is added in Figure A-54

Eventually based on this analysis, it can be said that without incentive/grants or income tax exemption, solar PV models would not be an economically feasible option to implement in industrial scale comparing to the current electricity export rate. Solar PV projects can reveal new opportunities to secure power planning along with utilizing the potential of Bangladesh if the government has the plan to focus on utilizing renewable resources.

4.5.3 Wind Model

This section contains a discussion on sensitivity and risk analysis of all three wind models in RETScreen software. All three models show a negative result in this analysis. It shows that if all conditions remain as predicted, the project is not feasible.

Risk analysis was done on NPV considering 20% changes in input parameters, for instance, initial cost, electricity export rate, debt term, debt interest rate, O&M, and debt ratio. According to the analysis, initial cost, electricity export rate, debt interest rate, and debt term are the most important parameters having a large impact on NPV. Randomly generated datasets of NPV from Monte Carlo Simulation shows all negative values for all three models. A representation of the sensitivity analysis of a 5 MW wind model is shown in

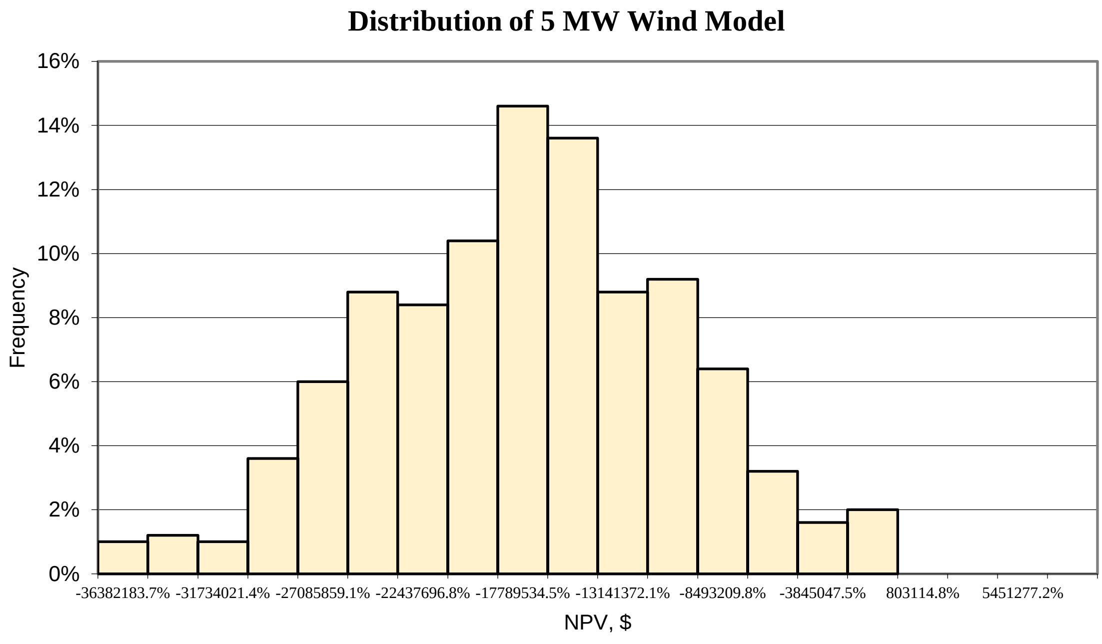
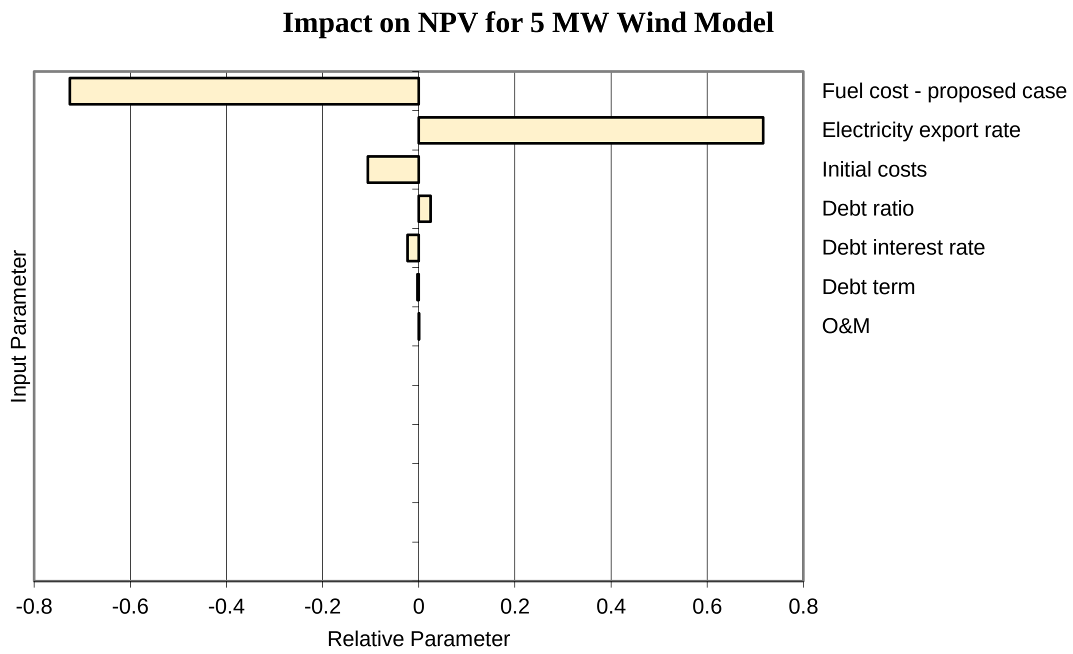


Figure 4-9. For 1 MW and 50 MW wind model, impact and distribution curves are added in Figure A-56 and Figure A-58.

Finally, the prospect of a wind project in Bangladesh might be risky based on the current situation of wind potential and current economic conditions. But there are rooms to explore if there is more wind potential at a higher elevation in Bangladesh or government grants or funds on initial investment or extended electricity rate that can make this project economically attractive.



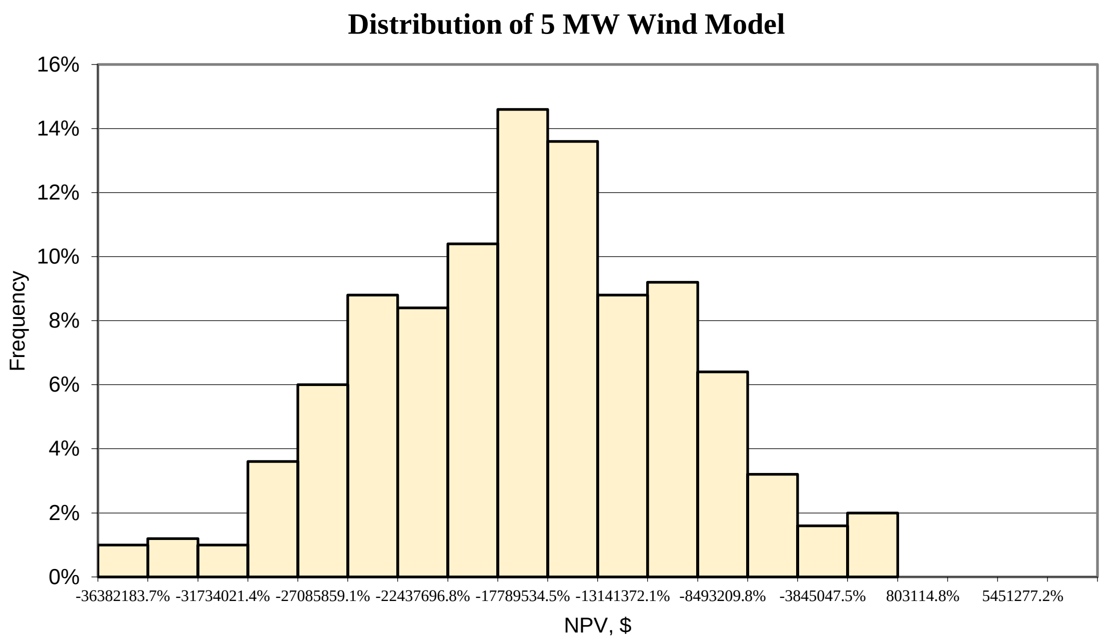
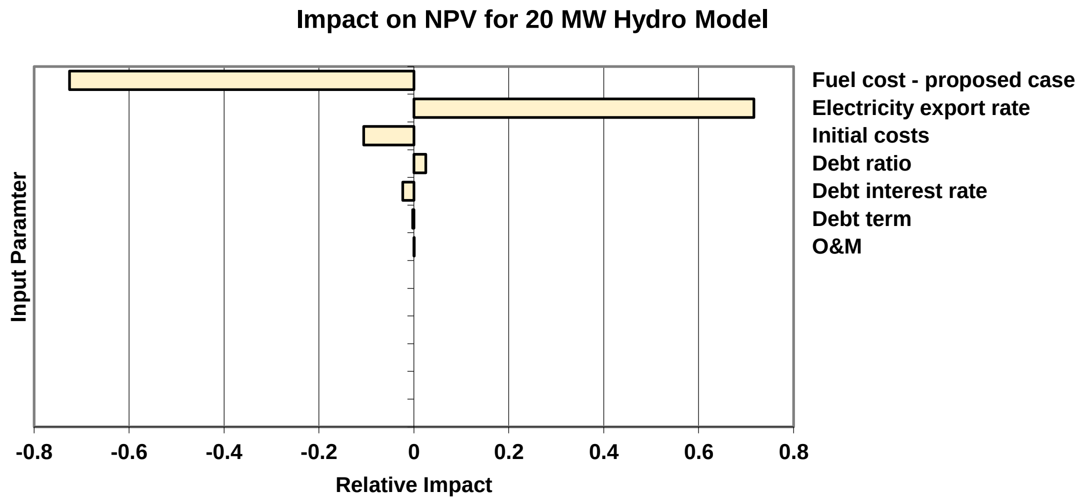


Figure 4-9: Sensitivity analysis of wind model with capacity 5 MW

4.5.4 Hydro Model

In this section, the sensitivity and risk factor of input parameters to important financial indicators were briefly explored for RETScreen hydro models. Sensitivity analysis calculates the percentage of changes of financial outputs, for example, after-tax IRR equity, after-tax IRR assets, equity payback, NPV due to changes in input parameters in a tabular form.

From this analysis, 1 MW hydro model calculated changes of after-tax IRR equity in a range of (-0.1~2.7) %, which is well below the threshold limit of 15%. Similarly, the 20 MW model measured after-tax IRR equity in a range of (10~19) % due to ±20% changes of input parameters. It contained around 50% values below the threshold limit of 15%, which means after-tax IRR equity was sensitive to fuel cost, initial cost, and debt interest rate. Any increase in fuel cost, initial cost or debt interest rate could affect after-tax IRR equity to a value lower than 15%.



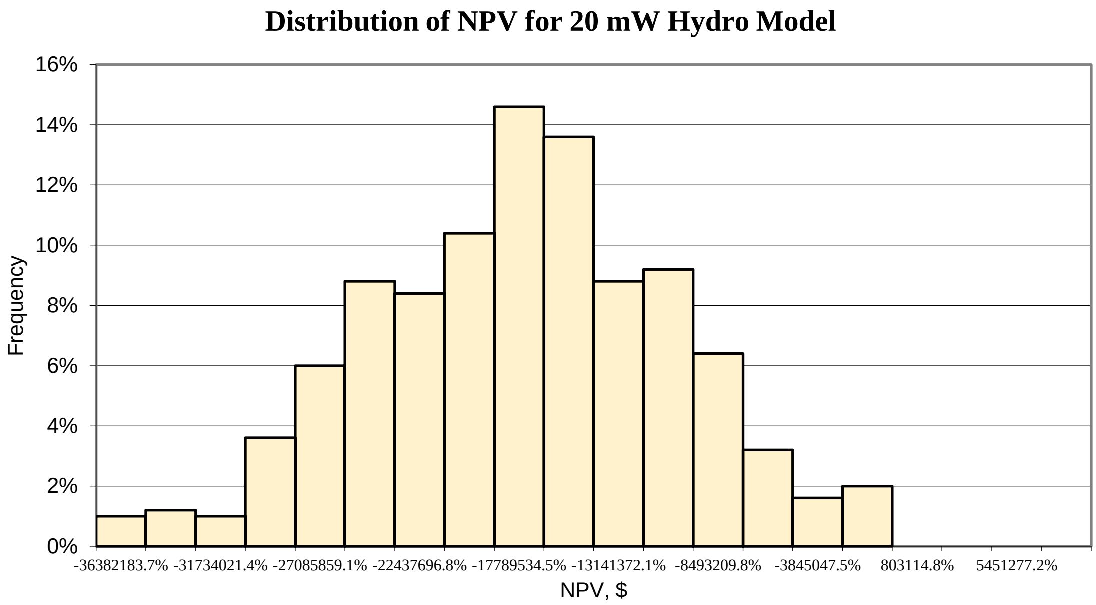


Figure 4-10: Sensitivity analysis of the hydro model with capacity 20 MW

Risk analysis estimates risk in terms of relative impact factor of input parameters using standardized multiple linear regression on the financial indicator. The outcome from this analysis is shown as an impact chart and a probability histogram. This analysis was performed on NPV for both models considering ±20 % changes in electricity export rate, initial cost, O&M, debt ratio, debt interest rate, and debt term. Initial cost, electricity export rate, and O&M had the largest impact on NPV due to the changes in input parameters for both models. Assuming a 10% level of risk, minimum and maximum level of confidence for 1 MW model were found negative. 20 MW model estimated minimum and maximum level of confidence as $39 million and $68 million. The impact graph and probability histogram of this analysis is also shown in Figure 4-10 for 20 MW hydro model. For 1 MW hydro model, these curves are included in Figure A-60.

This analysis showed a good hydro potential at Sangu J39 site. 20 MW hydropower project would be an economically attractive option although low electricity export rate and high initial cost were found the most sensitive factor for this project. An extended electricity export rate or incentive or grant on investment can attract financial investors of this project. After all, it can be a good addition to the existing sole Kaptai hydropower plant to increase the contribution of renewable resources of Bangladesh.

5. CONCLUSIONS AND RECOMMENDATIONS

Bangladesh is attempting to thrive in developing a strategic energy policy to ensure the security of energy supply, and availability at affordable prices. Diversifying energy resources and utilizing domestic renewable resources are significant approaches to this. The main objective of this study is to analyze the feasibility of potential renewable resources of Bangladesh by energy modeling with RETScreen software. It includes reviewing technical features, evaluating financial and economic viability, measuring environmental impact, and understanding potential risks of biomass, solar, hydro, and wind models.

Based on the current electricity export rate, small scale solar home project of 5 kW and the hydro model at Sangu having capacity of 20 MW were found promising. However, large scale solar PV project need financial support from the government. Biomass and wind projects also need financial assistance from the government or other organizations to make it economically viable according to the current context of Bangladesh due to having a high capital cost and a low-capacity factor of both biomass and wind to the electricity conversion process. These analyses and outcomes might be worthwhile for current projects to understand future impacts and associated risks. It can also work as a standard for future analysis of similar projects.

To adapt renewable projects in national grid, some policy implications are needed. Policy support for collection and distribution of waste biomass is one of those. Additionally, subsidy is also required for biomass projects. Solar technology is advancing day by day. It has a very good prospect in near future. Due to low potential and high capital cost wind projects are not financially feasible. Hydro projects need further study and specific hydrological data in potential sites before investment.

Moreover, some other policy implications are also required to amend the changes and make the national energy policy robust.

- Specific roadmap to achieve goals.
- Identifying challenges for transition from fossil fuel to renewable energy.
- Exact quantification of convertible renewable resource.
- Promoting renewable energy.
- Effort to explore and identify the best use of the renewable potential in terms of technology, location or capacity.
- Sharing best practices.
- Awareness raising, training, and collaboration.
- Inclusion of climate change policy including LEDS (Low Emission Development Strategy).
- Yearly review of targets and achievements.

This study gives insight into the potential of renewable resources and impacts after utilizing these in the next 20 to 30 years in Bangladesh. It also gives knowledge about the importance, benefits, and convenience of energy modeling in energy planning and the decision-making process. Any researcher, planner, or anyone working in a plant can also evaluate the performance and efficiency of the appliances or the process. This study can be beneficial to the policymaking process in the future or upgrading the current energy policy of Bangladesh.

Some parameters might change more or less than the assumed ones in the future which might change the overall result. This research was only performed on some selected capacity options which does not reflect the overall situation after implementation of all current or future projects. To understand the outcome, models having similar project capacity of both current and future projects considering different technologies need to be analyzed in the same process. After that, the overall impact and risk can be identified, and decisions can be made to optimize those risks. This research only focused on the impact of renewable resources, whereas a big contribution of conventional fossil fuel impact was not studied. In the future, there is a scope of study to anticipate the major impact of power generation from fossil fuel in Bangladesh.

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APPENDIX A

Appendix A.1 Figures from RETScreen Models

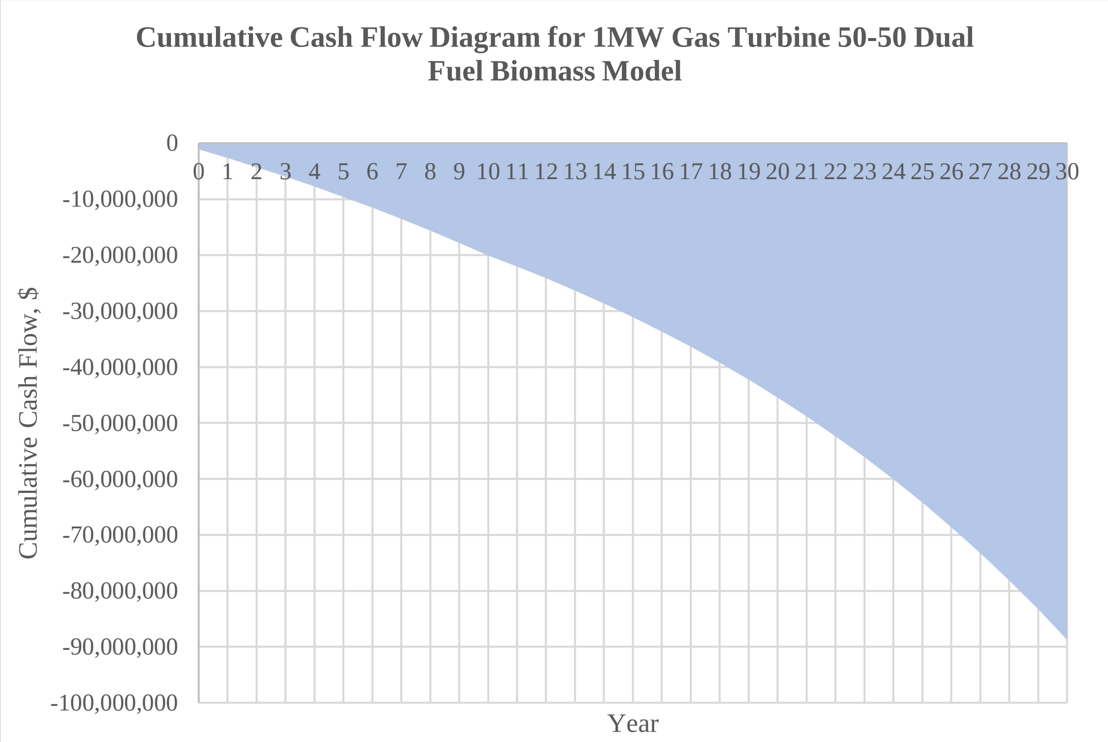
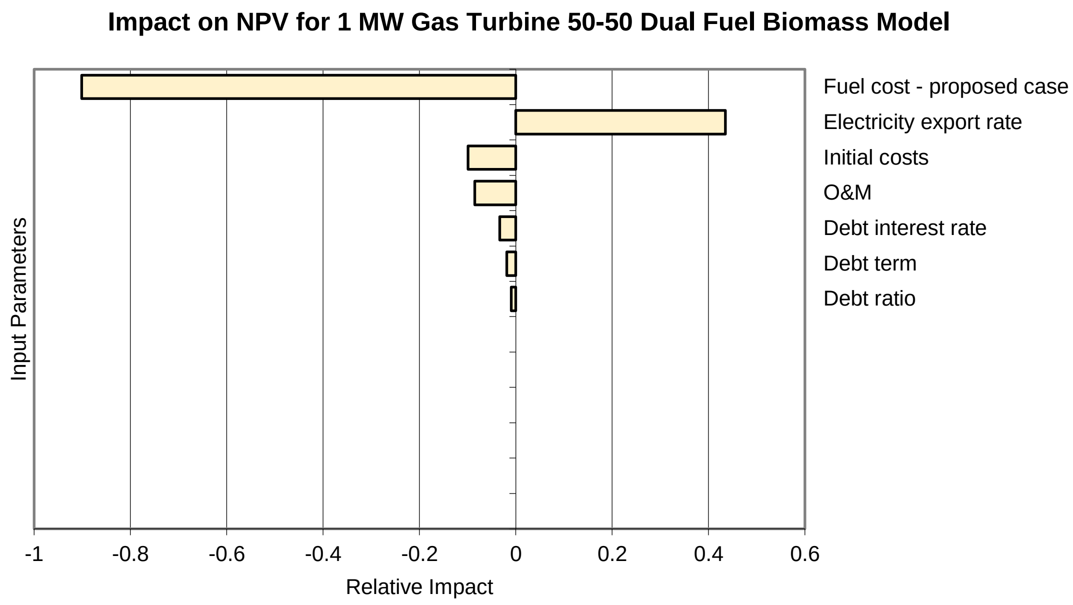


Figure A-1: Cumulative Cash-flow diagram for 1 MW Gas Turbine Biomass model having multifuel ratio 50-50 biomass-diesel



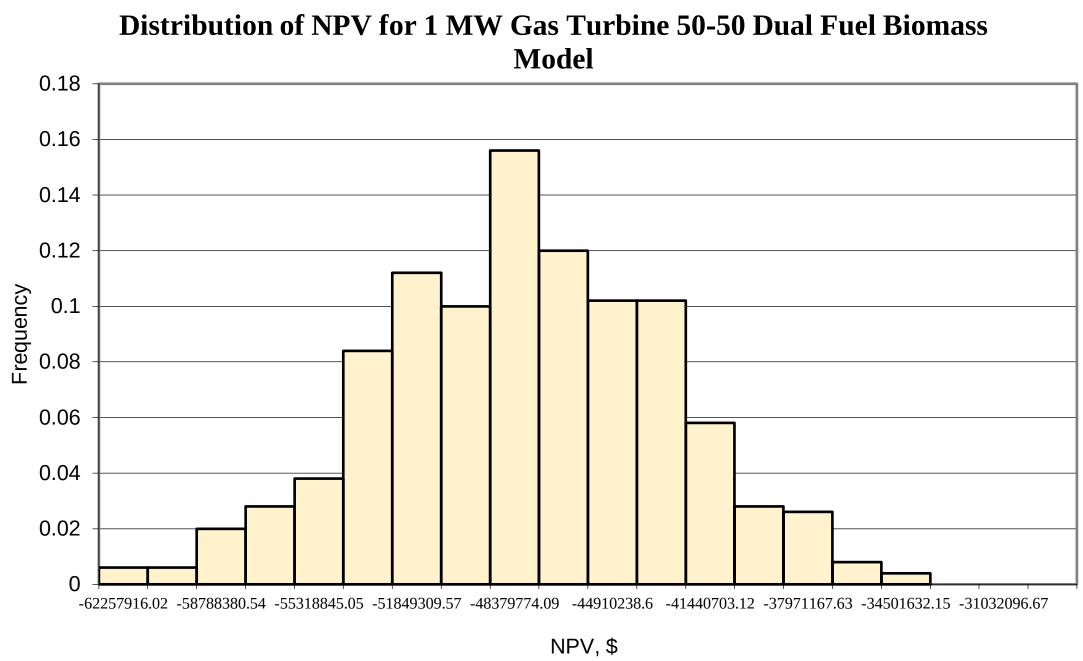


Figure A-2: Risk Analysis for 1 MW Gas turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel

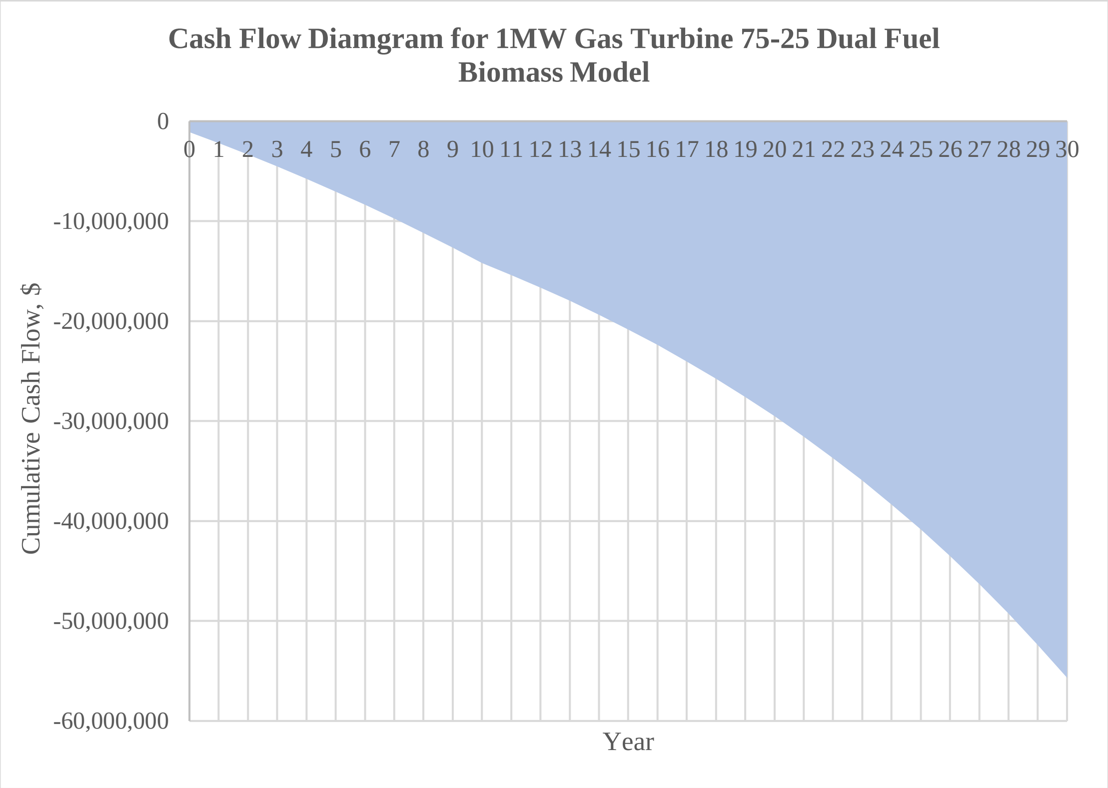
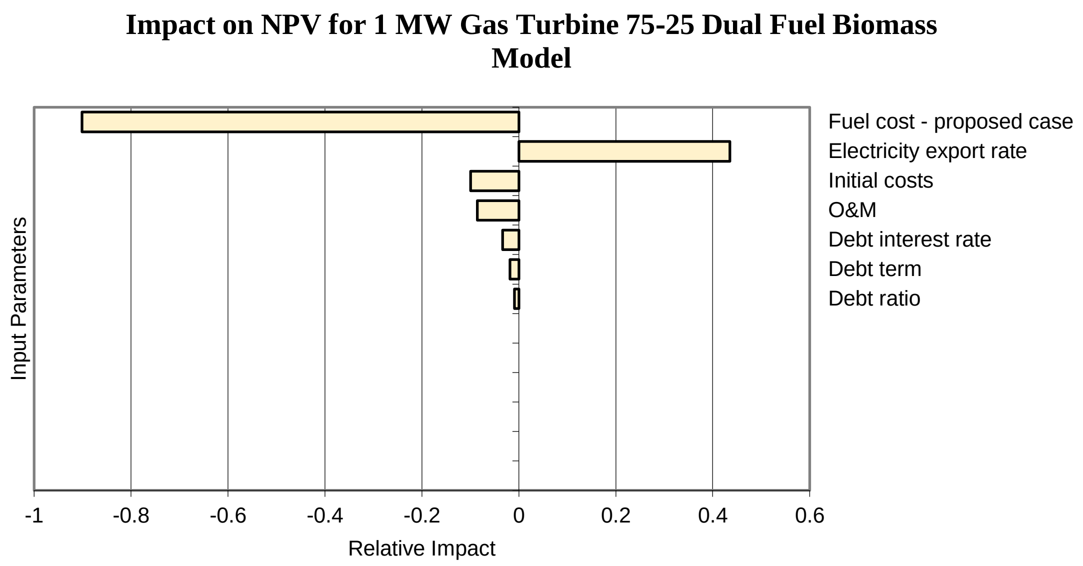
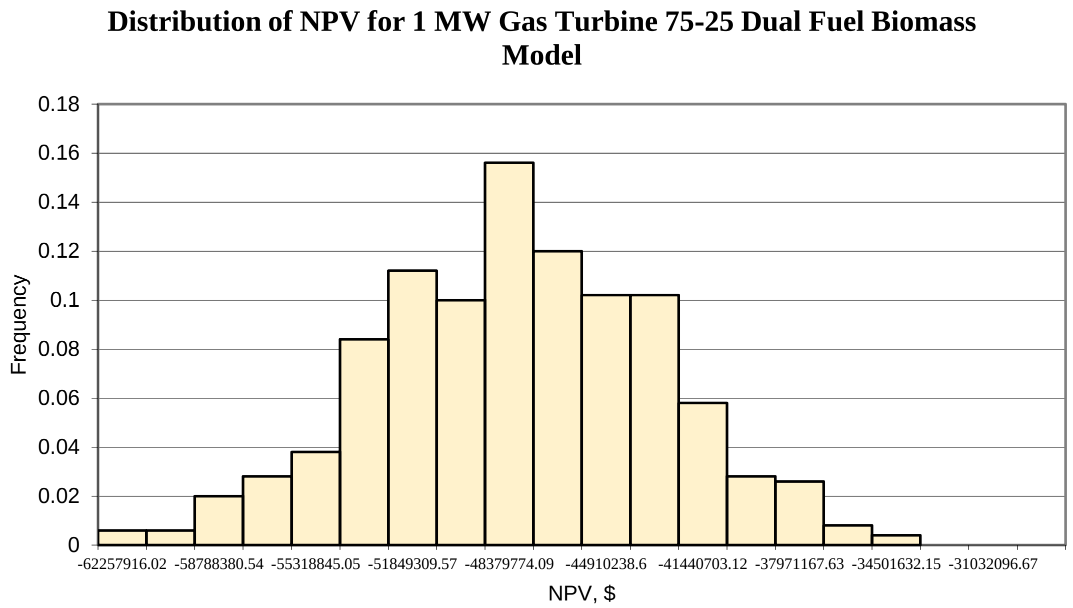


Figure A-3: Cumulative Cash-flow diagram for 1 MW Gas Turbine Biomass model having multifuel ratio 75-25 biomass-diesel





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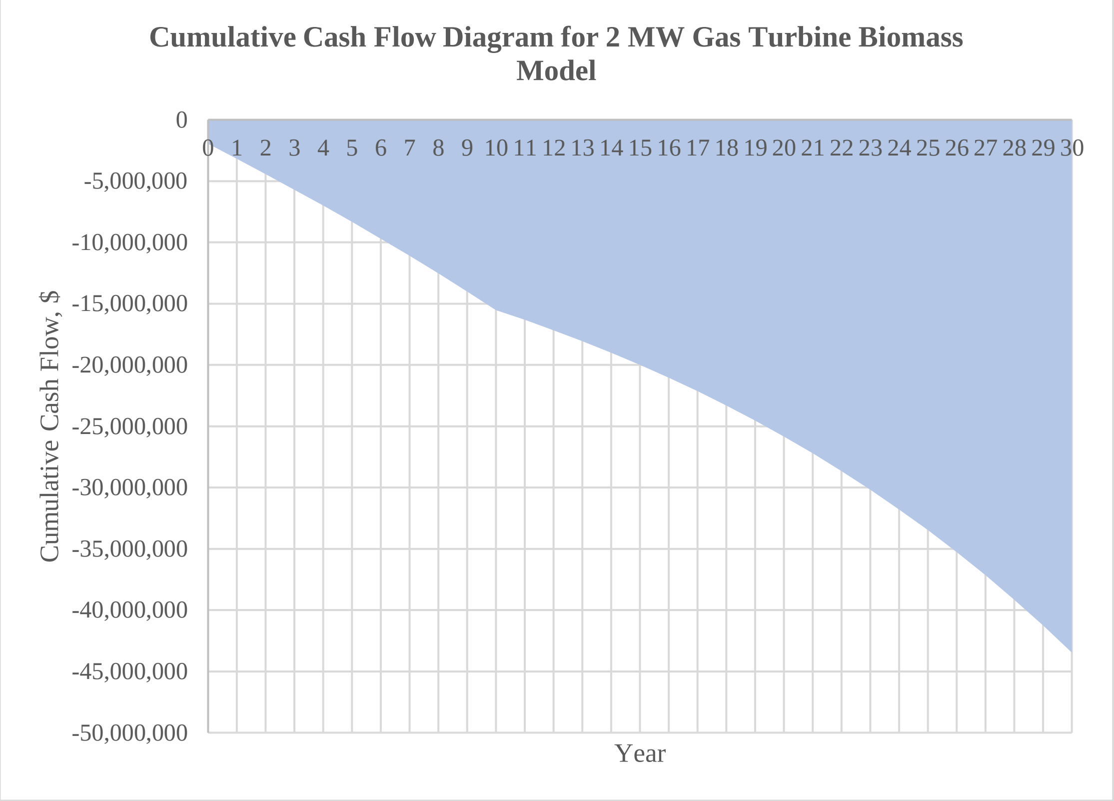
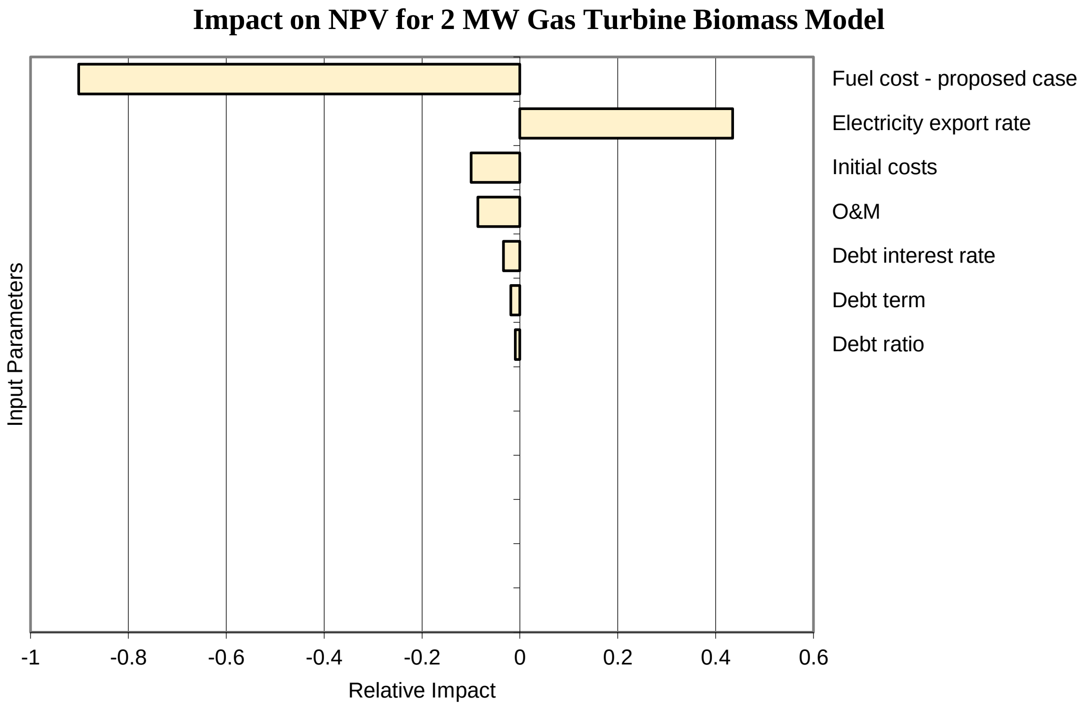


Figure A-5: Cumulative Cash-flow diagram for 2 MW Gas Turbine Biomass



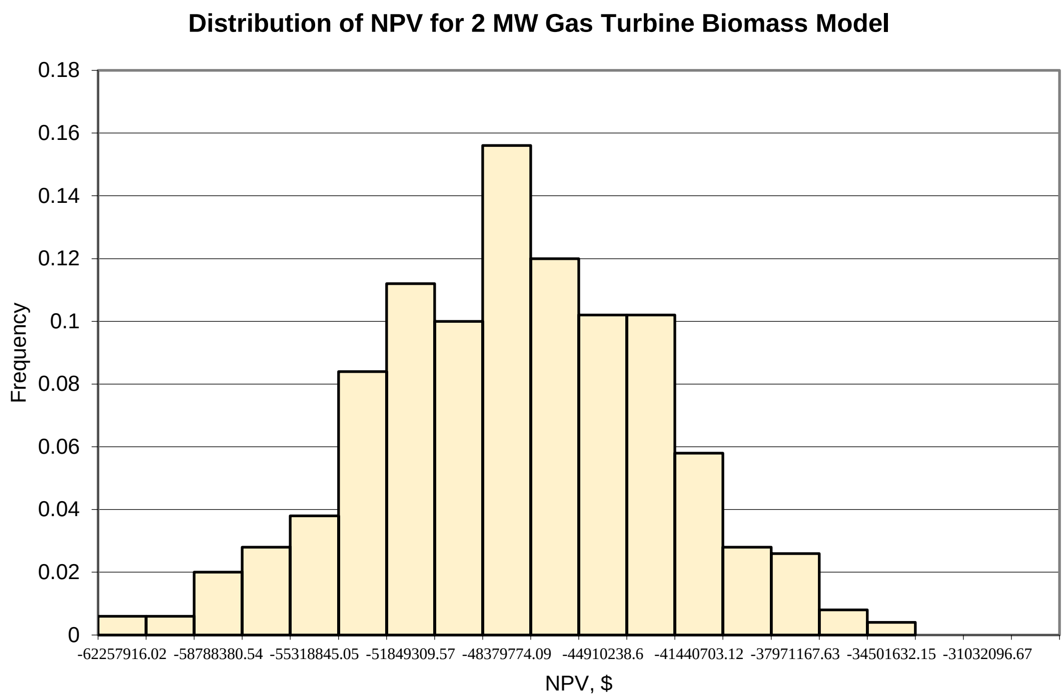
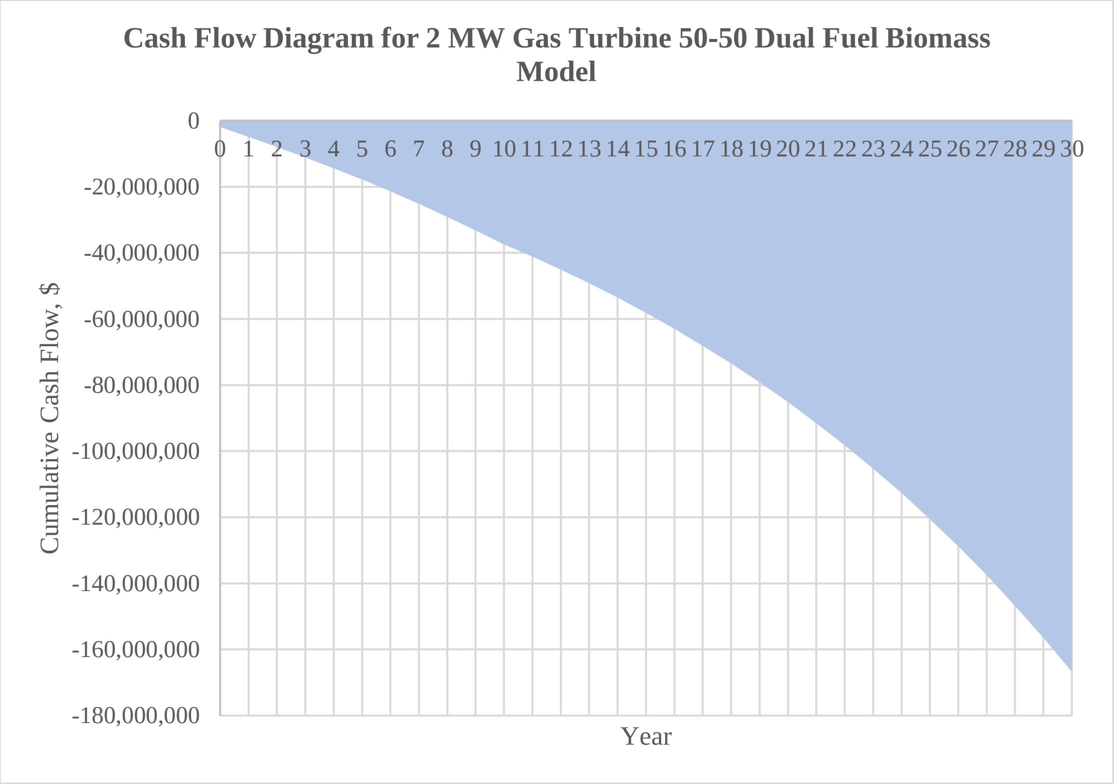


Figure A-6: Risk Analysis for 2 MW Gas turbine single cycle biomass



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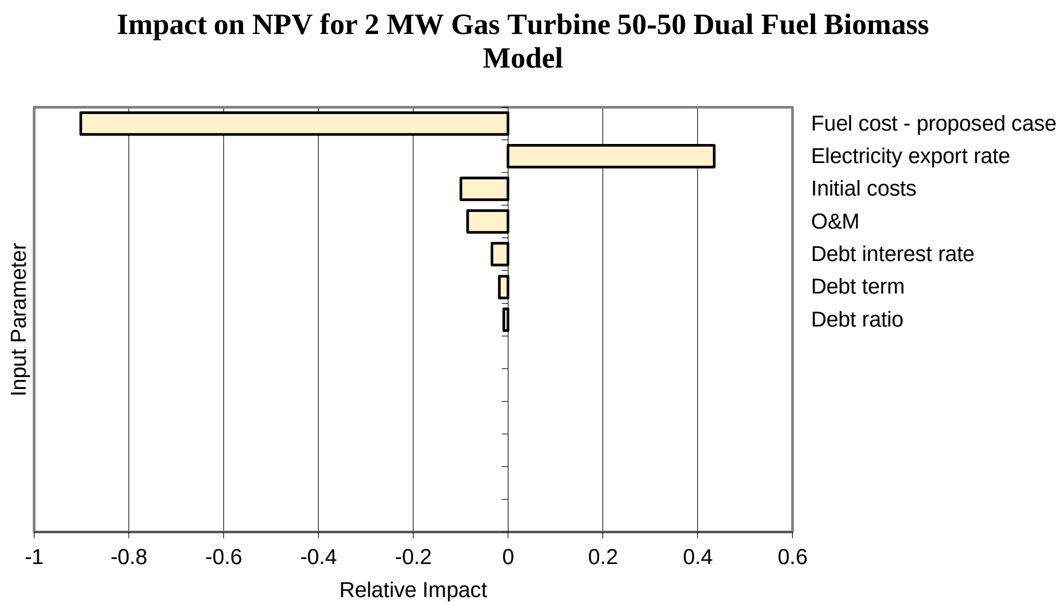


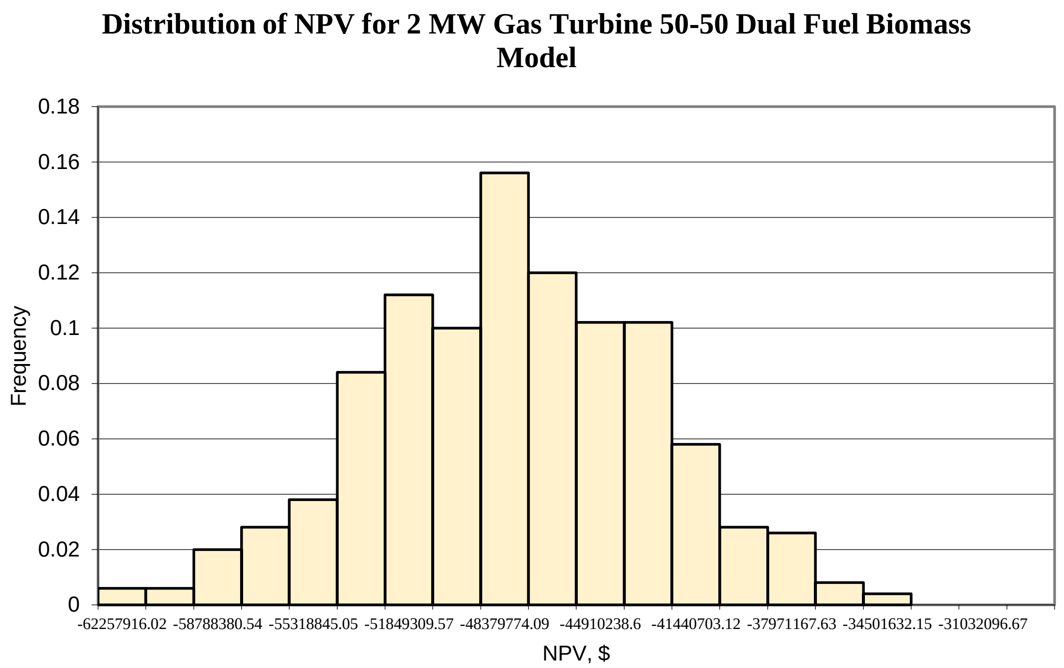
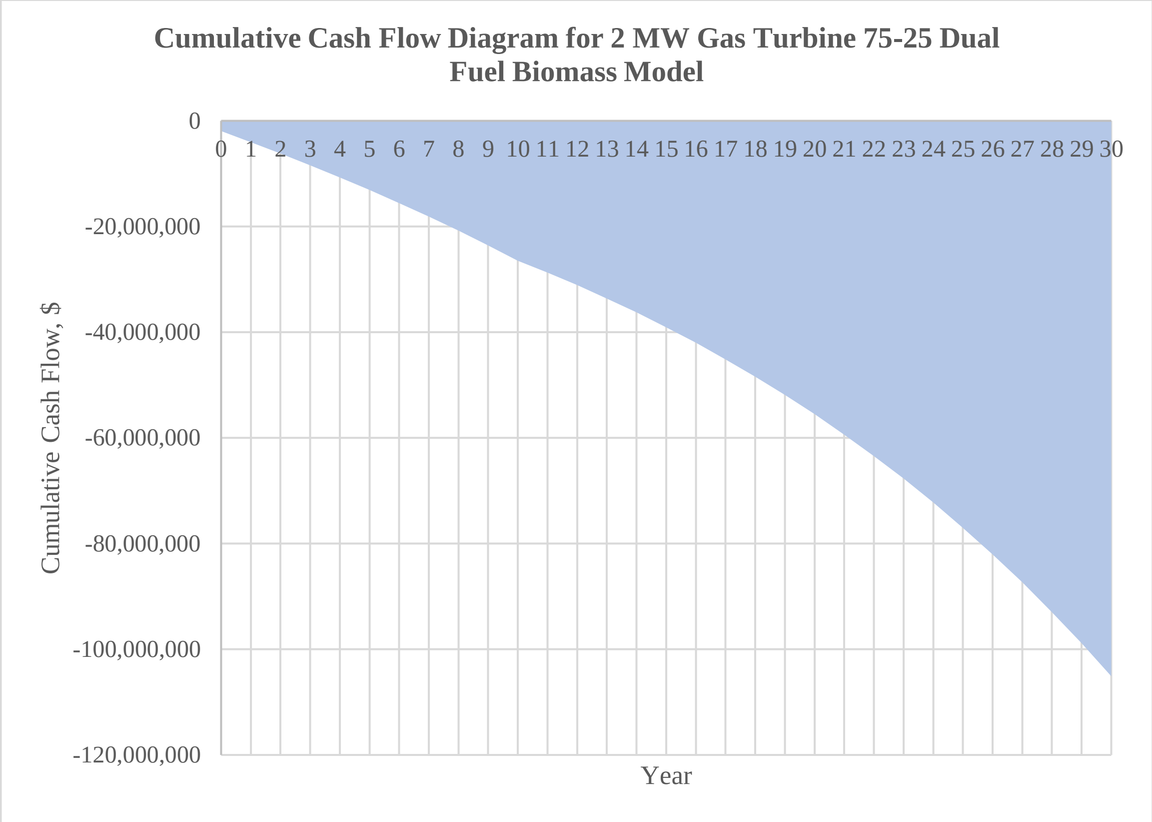


Figure A-8: Risk Analysis for 2 MW Gas turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel



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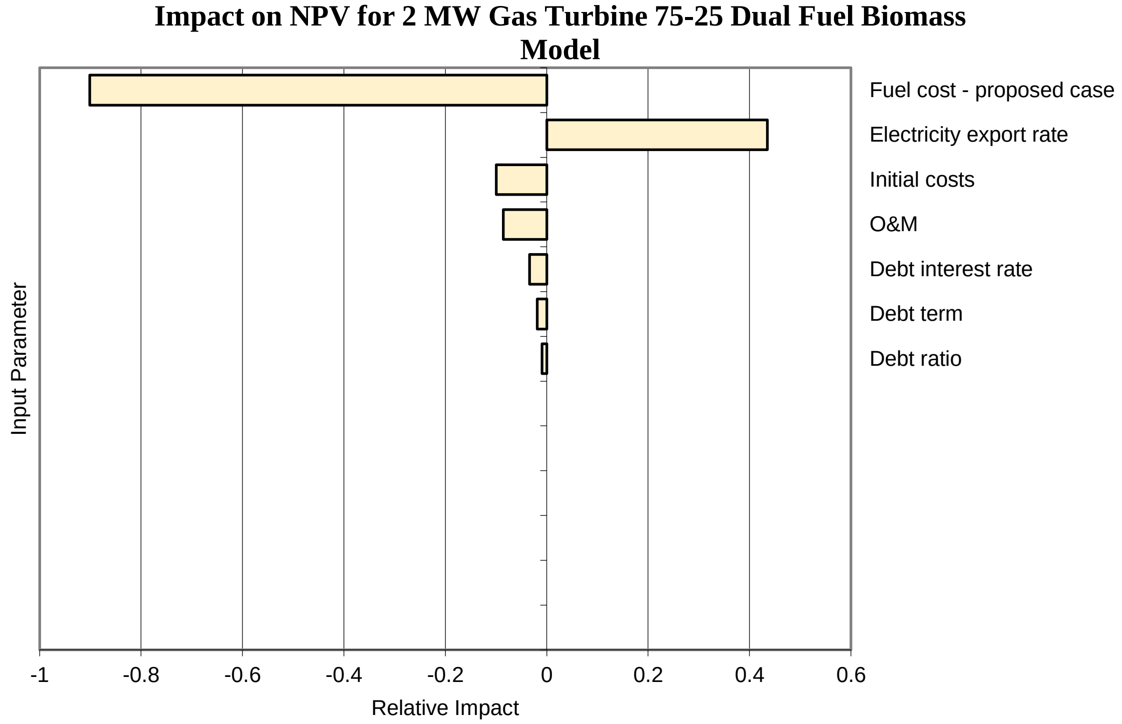


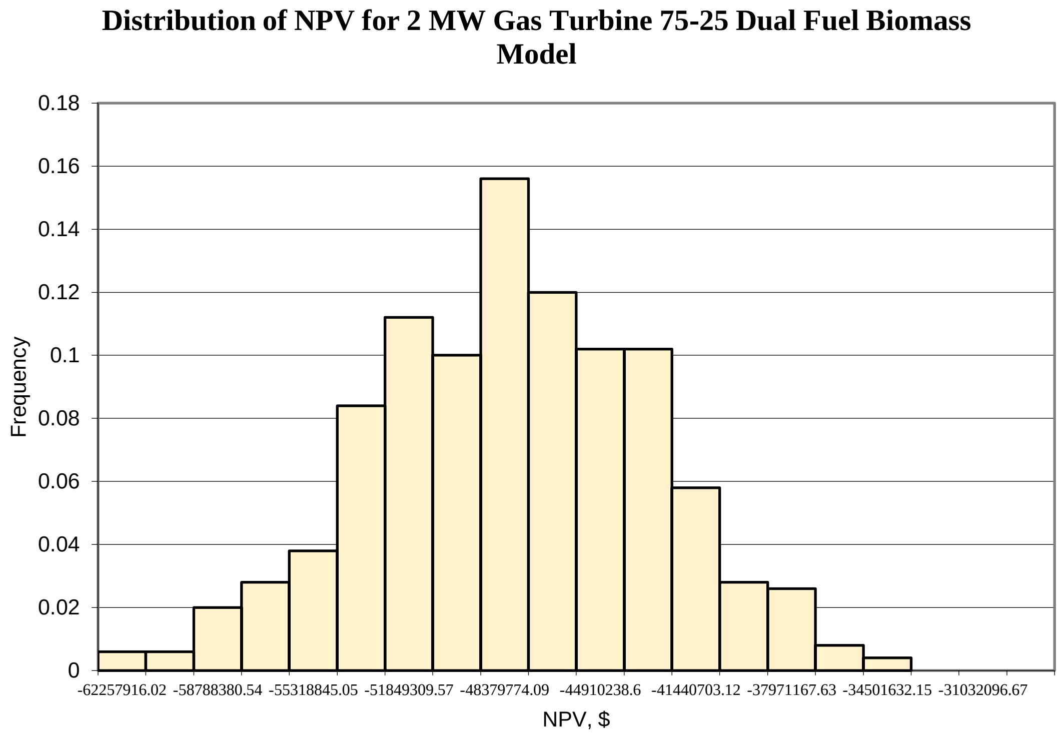


Figure A-10: Risk Analysis for 2 MW Gas turbine single cycle biomass model having multifuel ratio 75-25 biomass-diesel

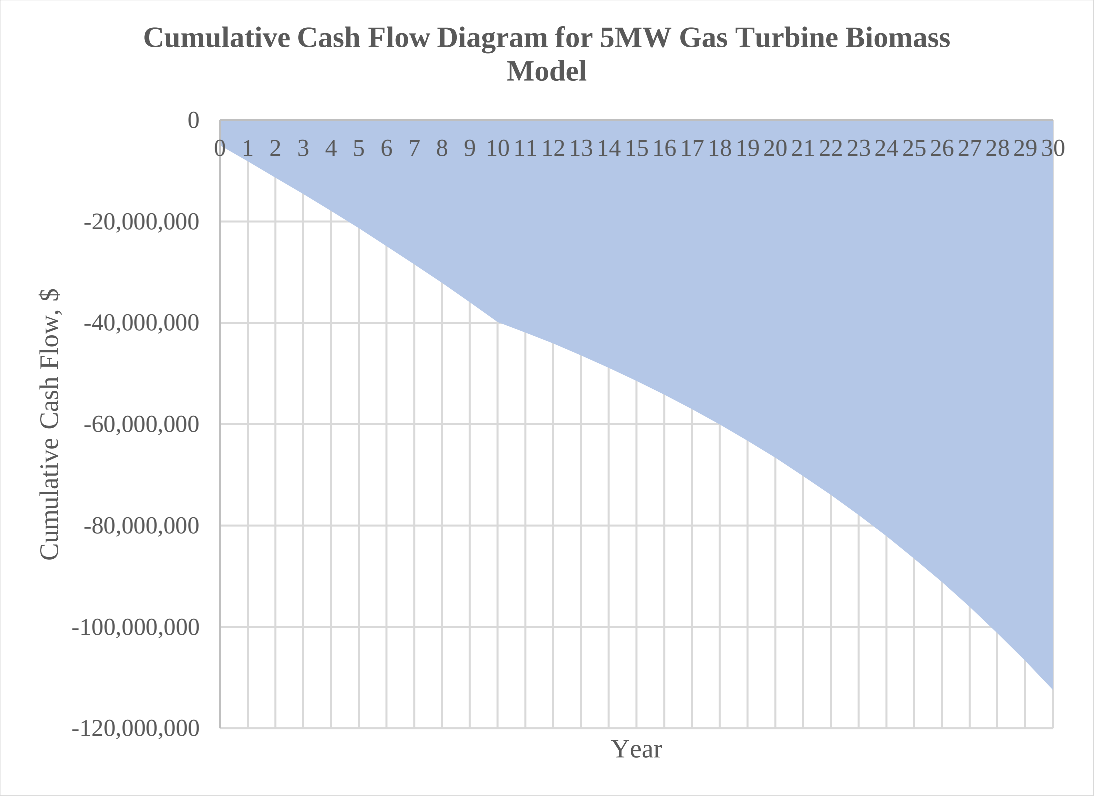
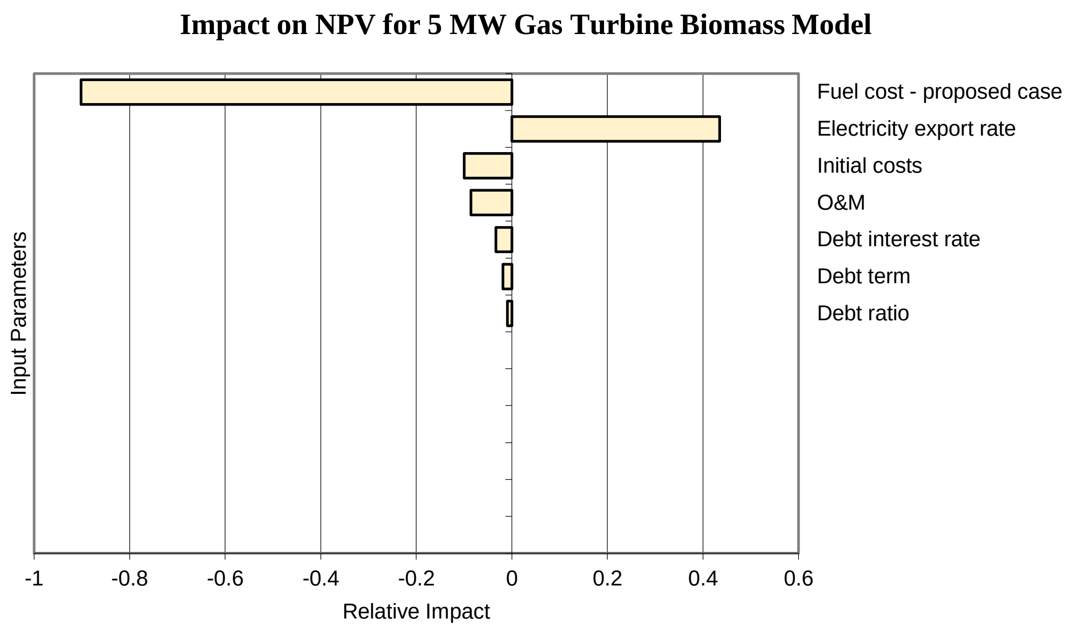
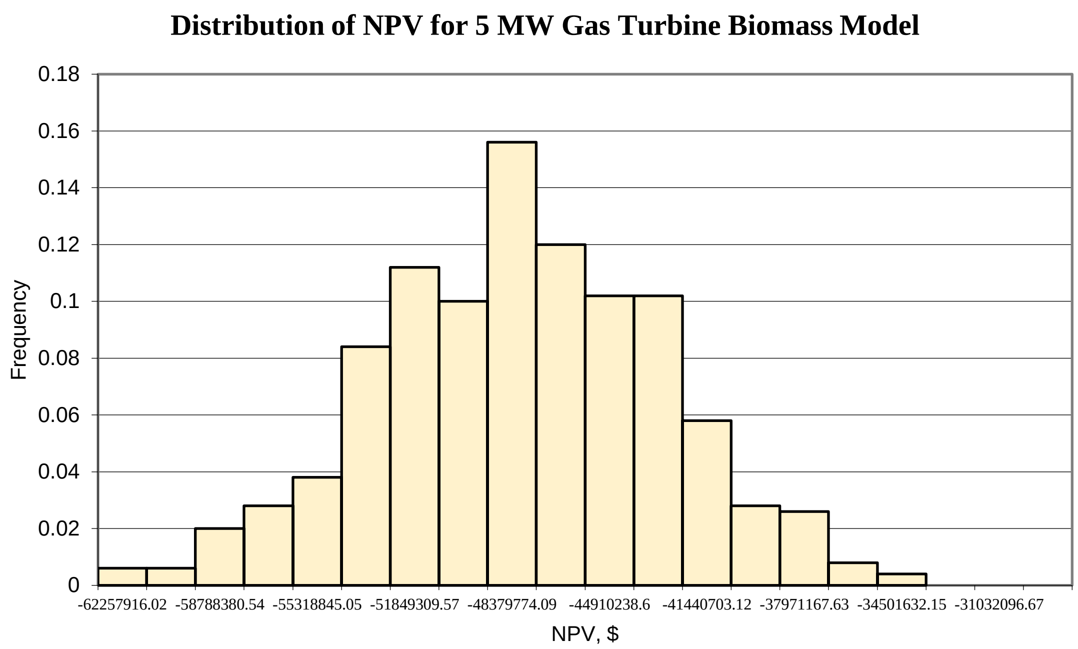


Figure A-11: Cumulative Cash-flow diagram for 5 MW Gas Turbine Biomass model





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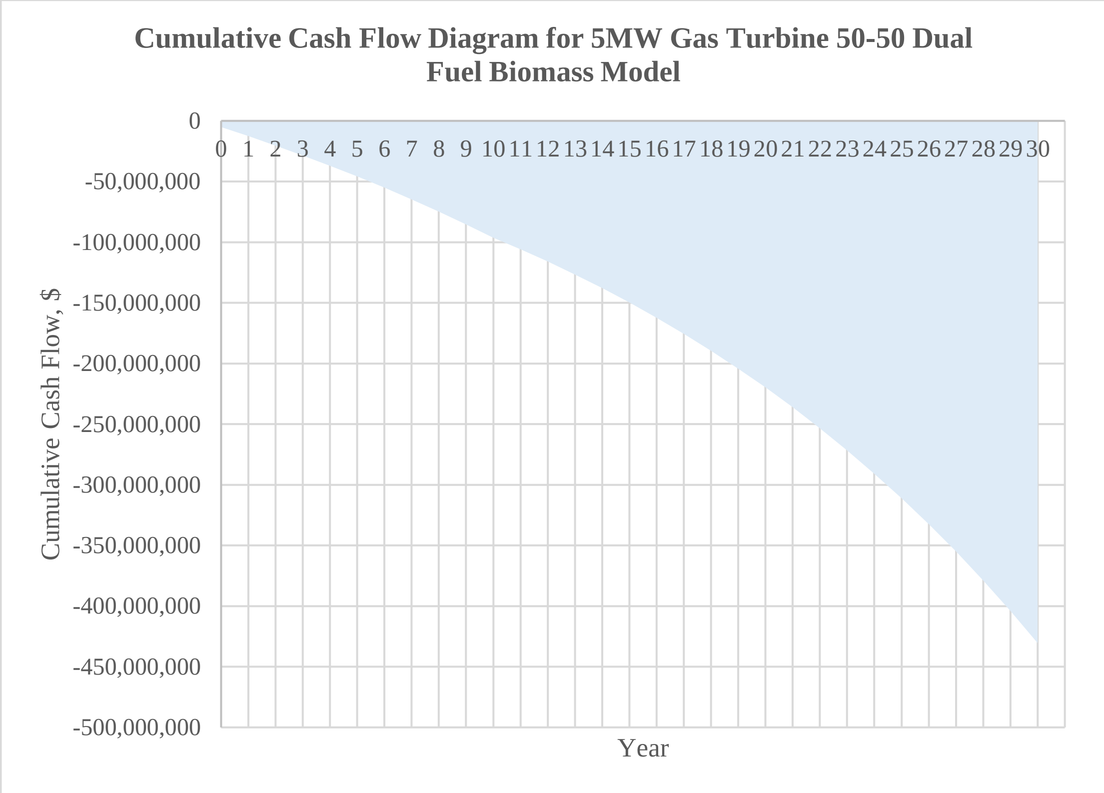
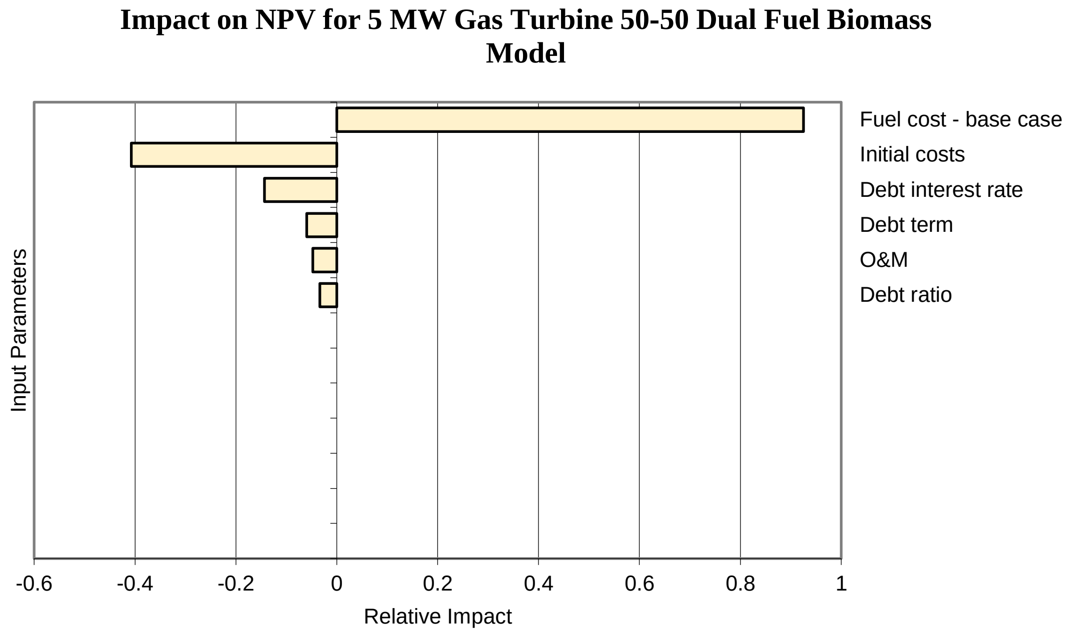


Figure A-13: Cumulative Cash-flow diagram for 5 MW Gas Turbine Biomass model having dual fuel *ratio 50-50 biomass-diesel*



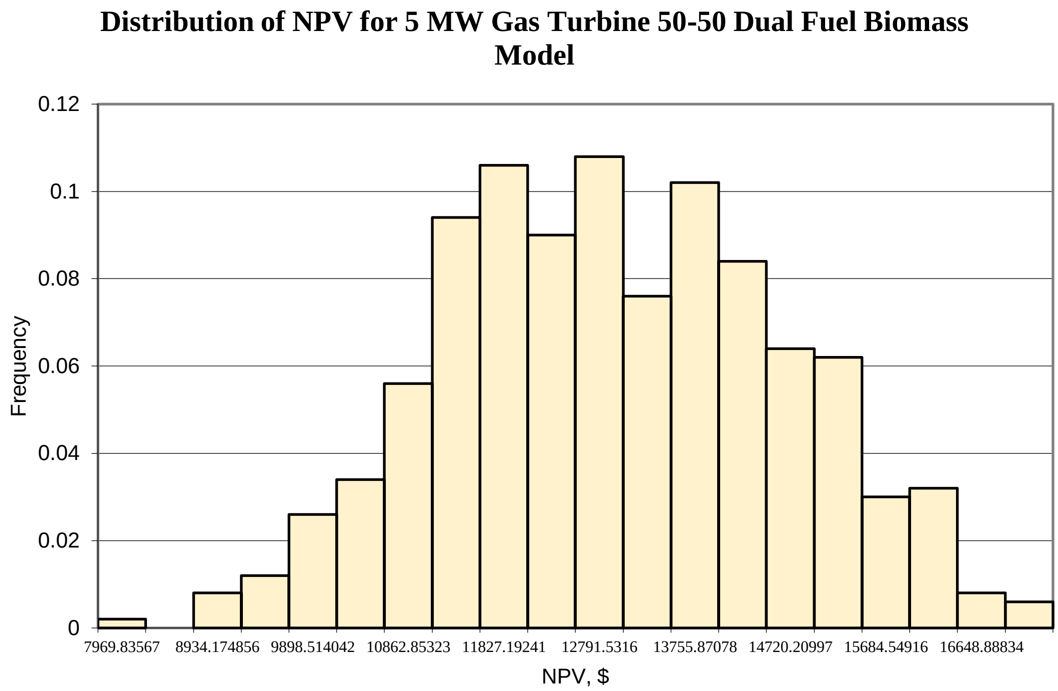


Figure A-14: Risk Analysis for 5 MW Gas turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel

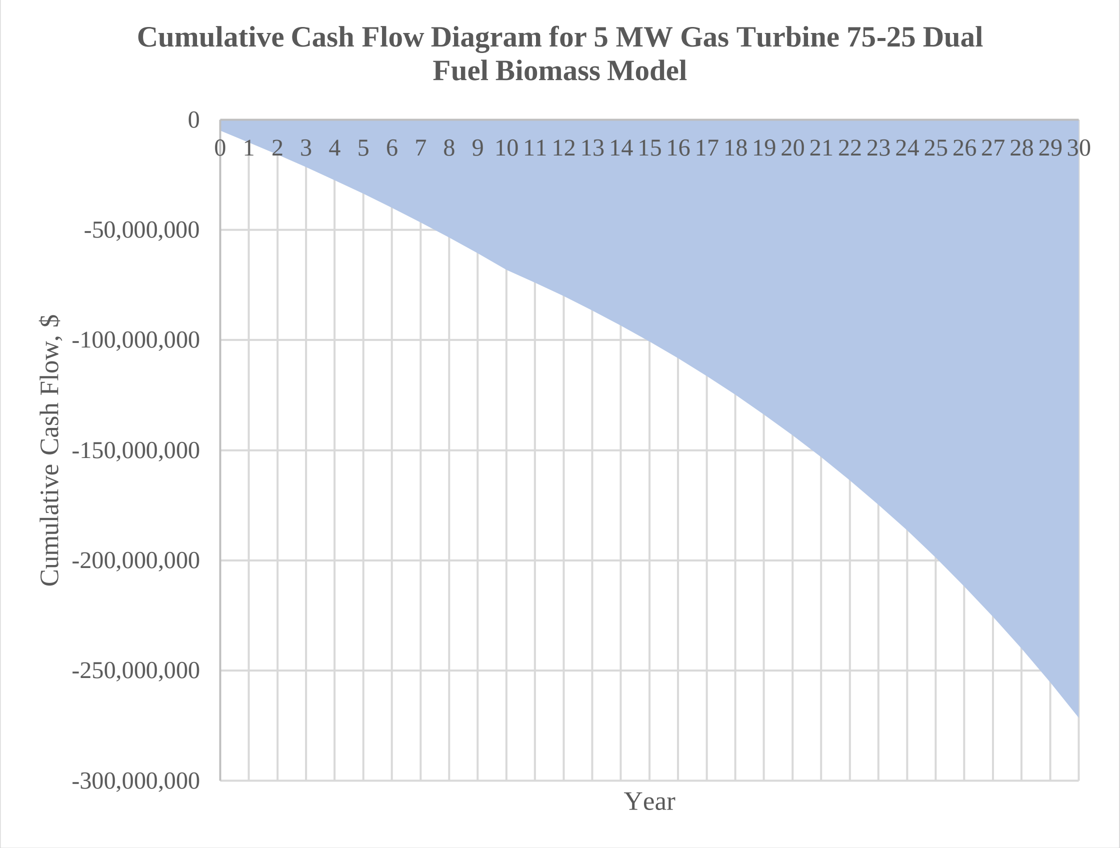
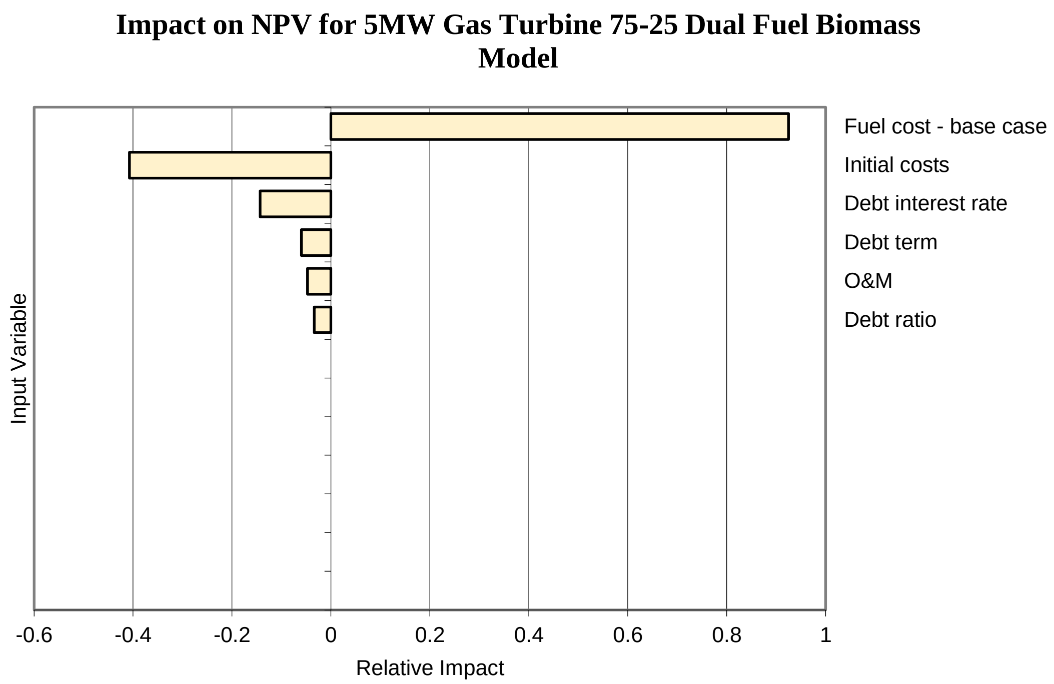


Figure A-15: Cumulative Cash-flow diagram for 5 MW Gas Turbine Biomass model having dual fuel *ratio 75-25 biomass-diesel*



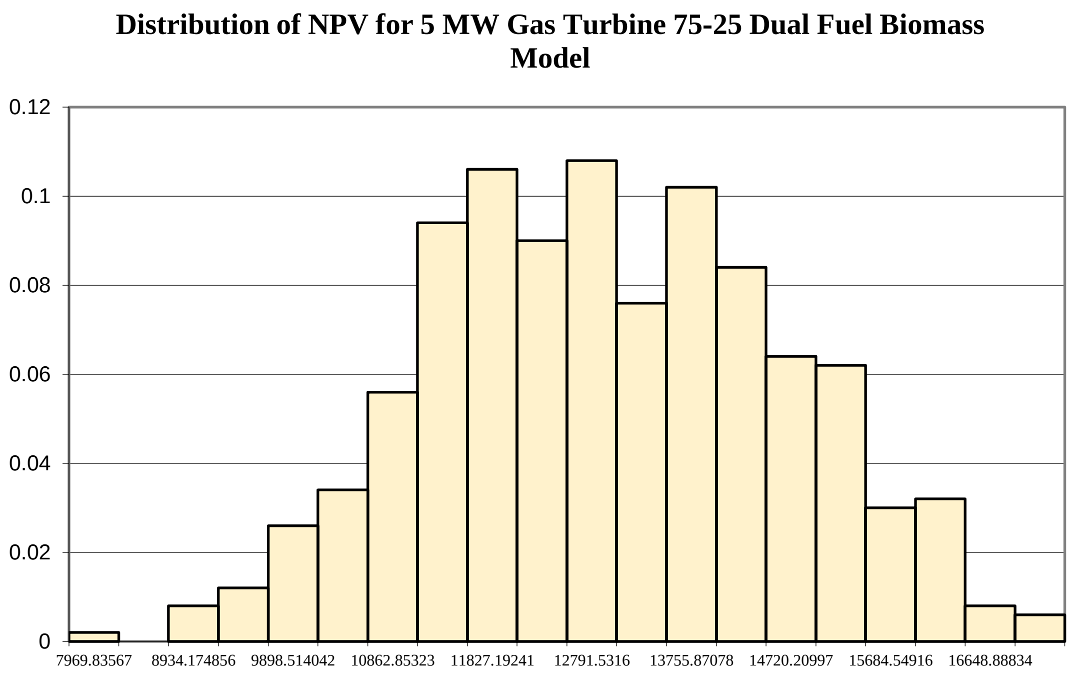


Figure A-16: Risk Analysis for 5 MW Gas turbine single cycle biomass model having multifuel ratio 75-25 biomass-diesel

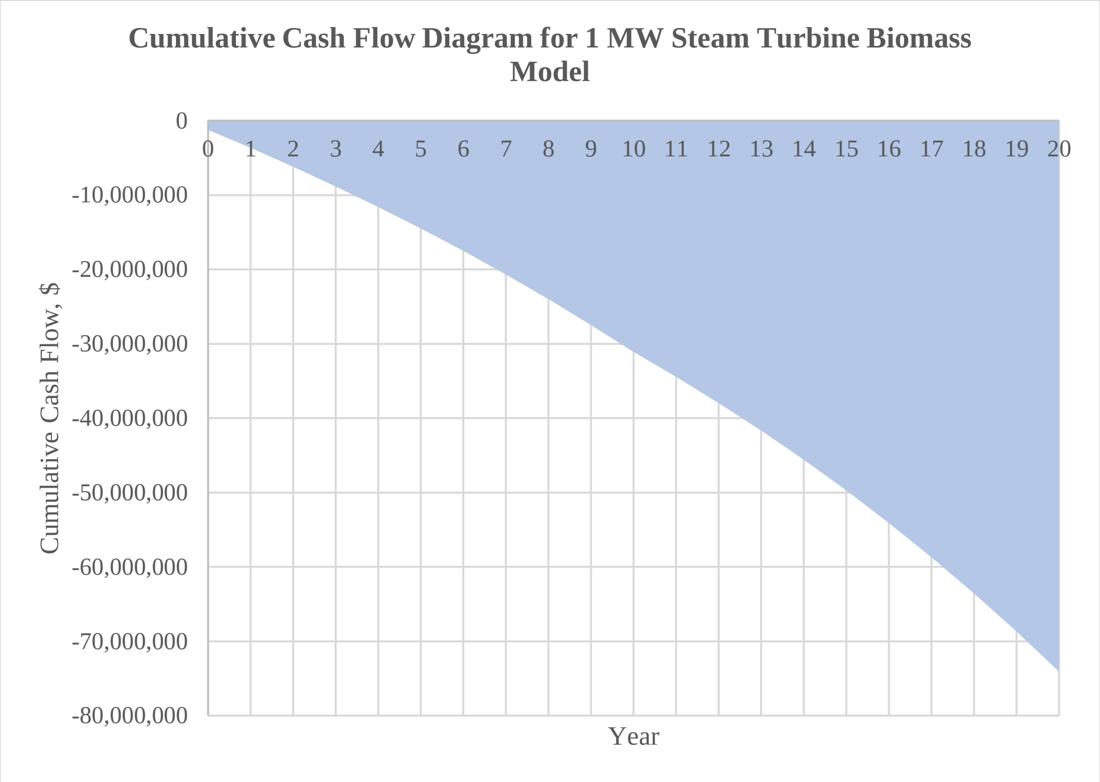
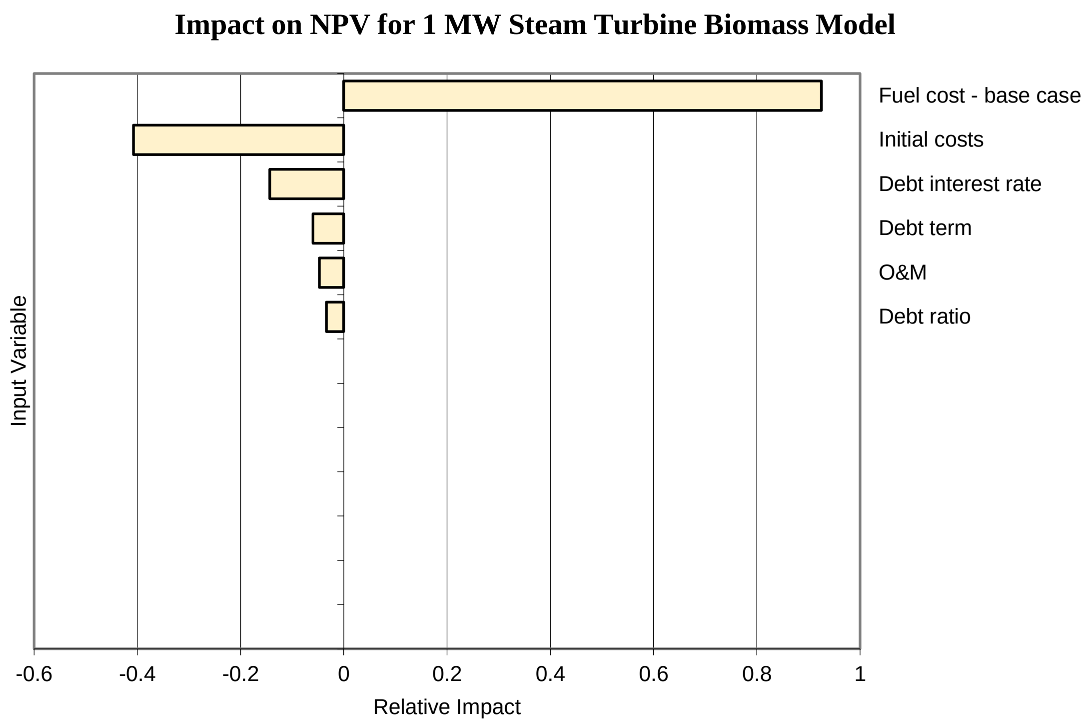


Figure A-17: Cumulative Cash-flow diagram for 1 MW Steam Turbine Biomass model



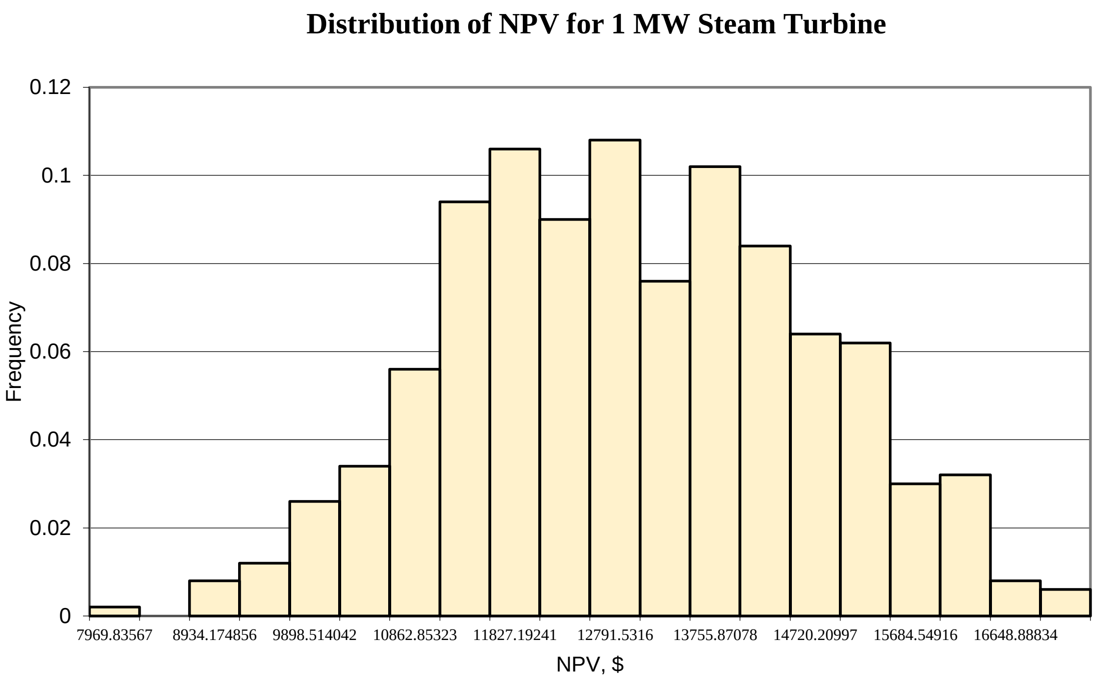


Figure A-18: Risk Analysis for 1 MW Steam turbine single cycle biomass model

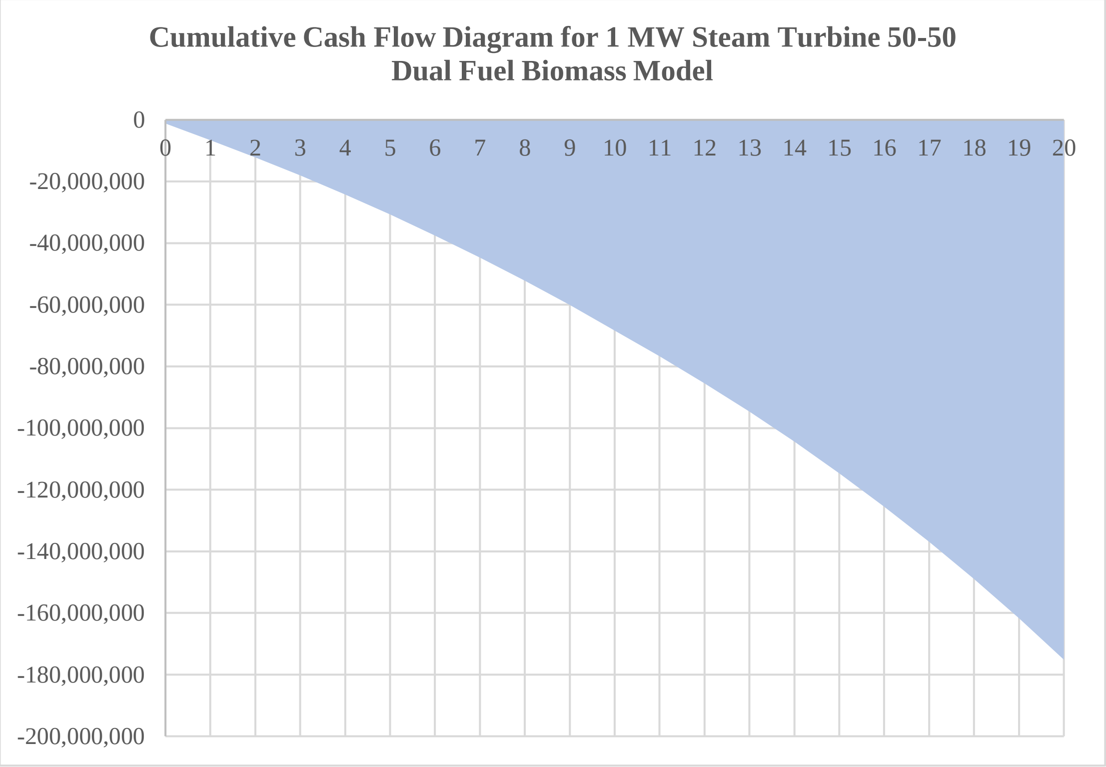
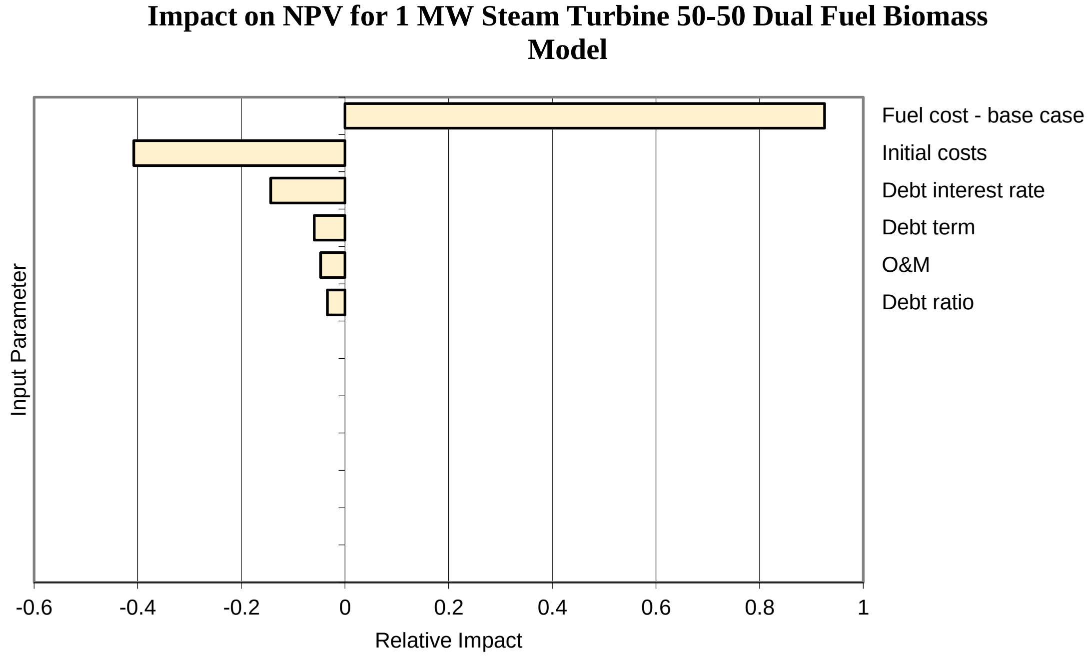


Figure A-19: Cumulative Cash-flow diagram for 1 MW Steam Turbine Biomass model having dual fuel *ratio 50-50 biomass-diesel*



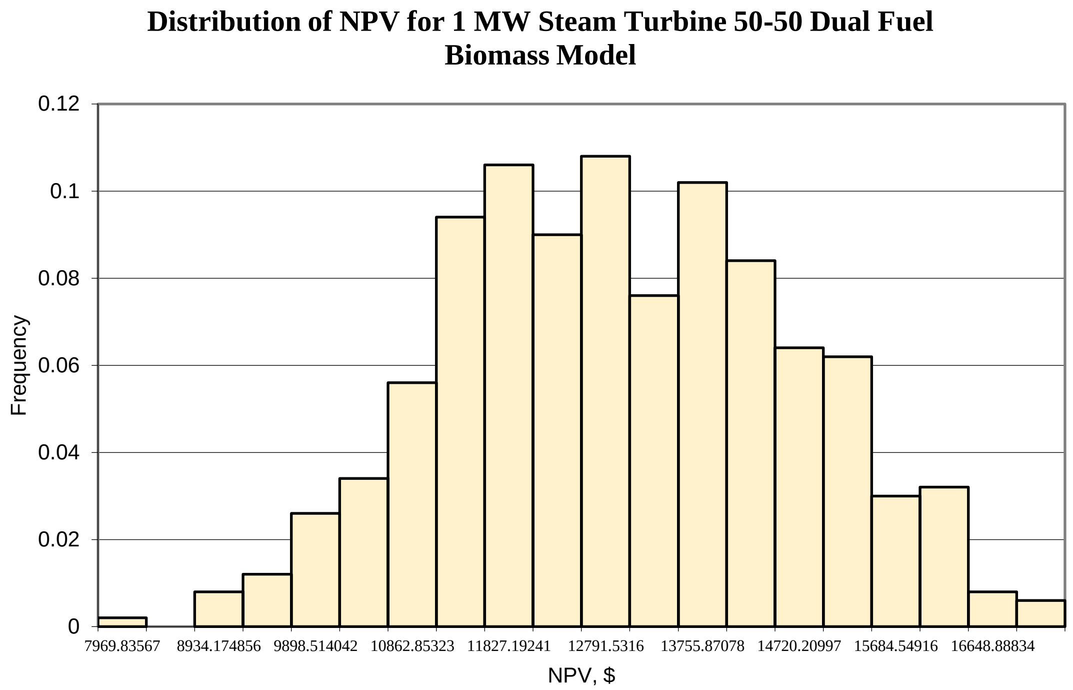


Figure A-20: Risk Analysis for 1 MW Steam turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel

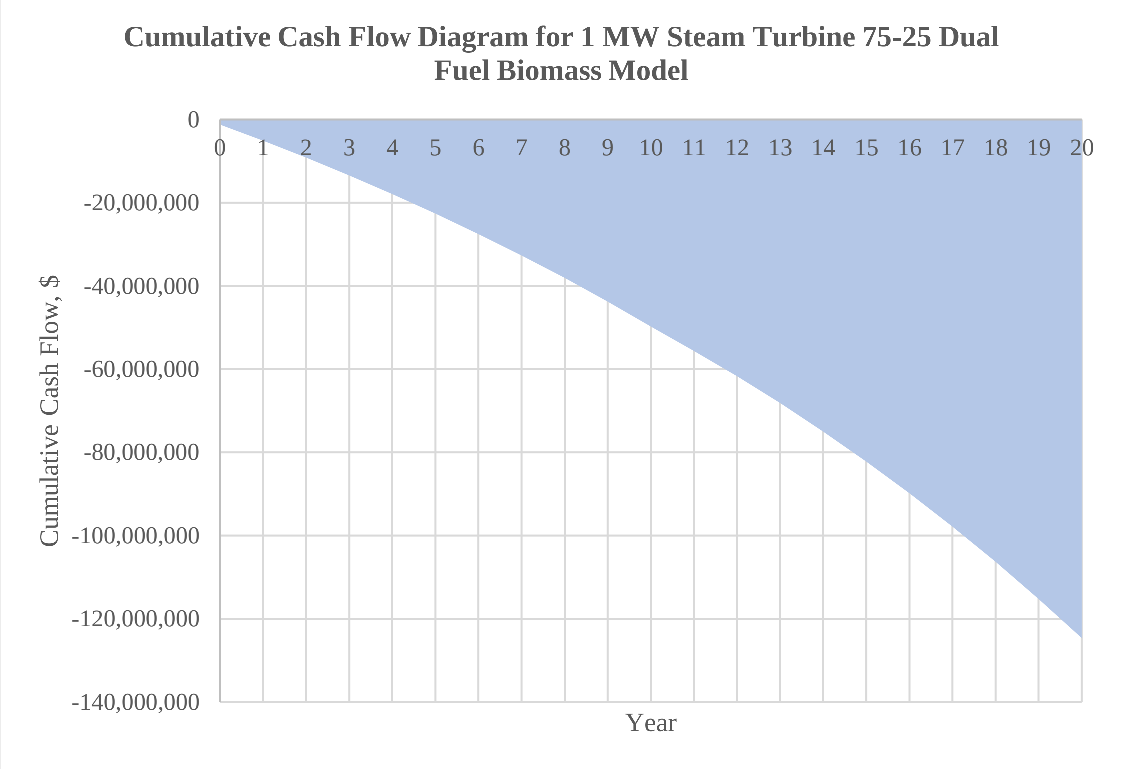
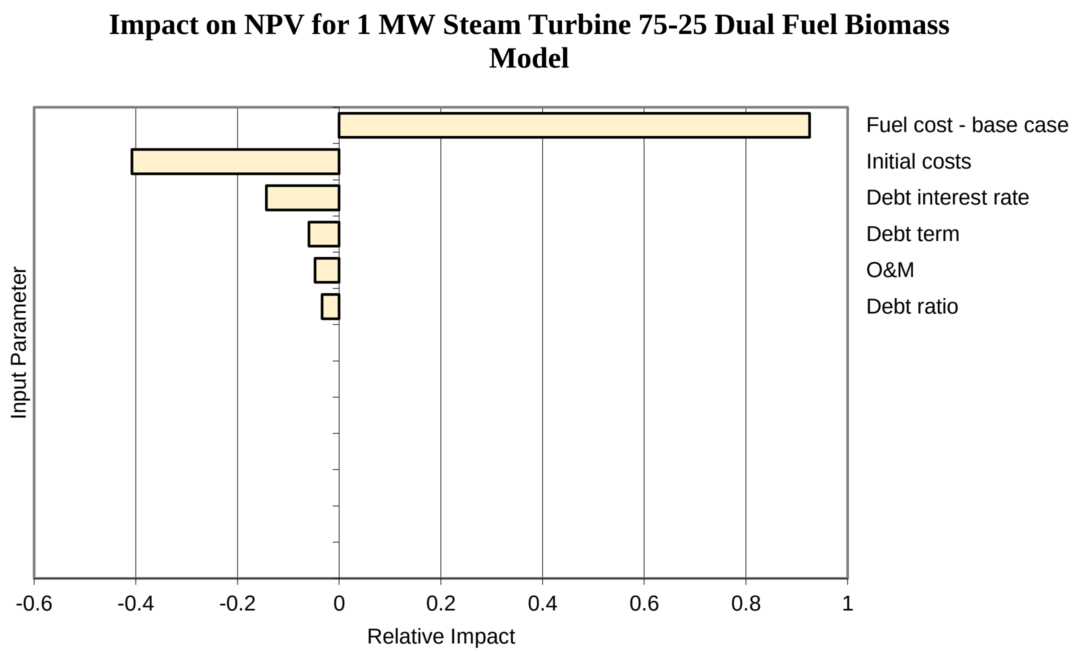
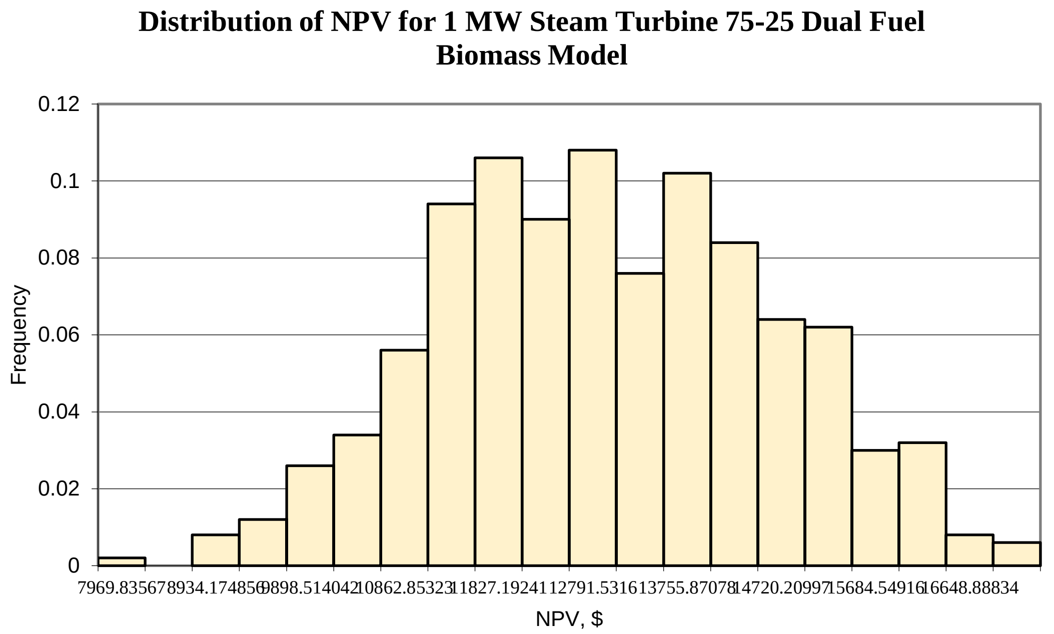


Figure A-21: Cumulative Cash-flow diagram for 1 MW Steam Turbine Biomass model having multifuel ratio 75-25 biomass-diesel





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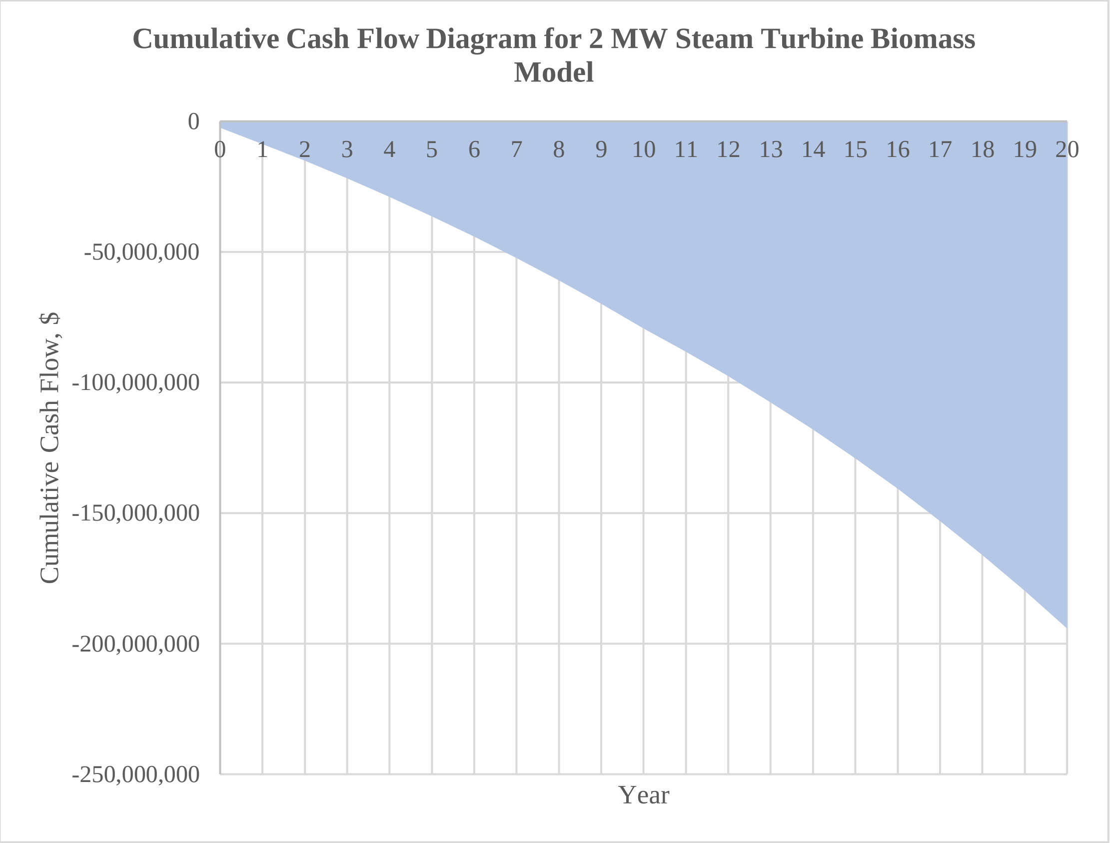
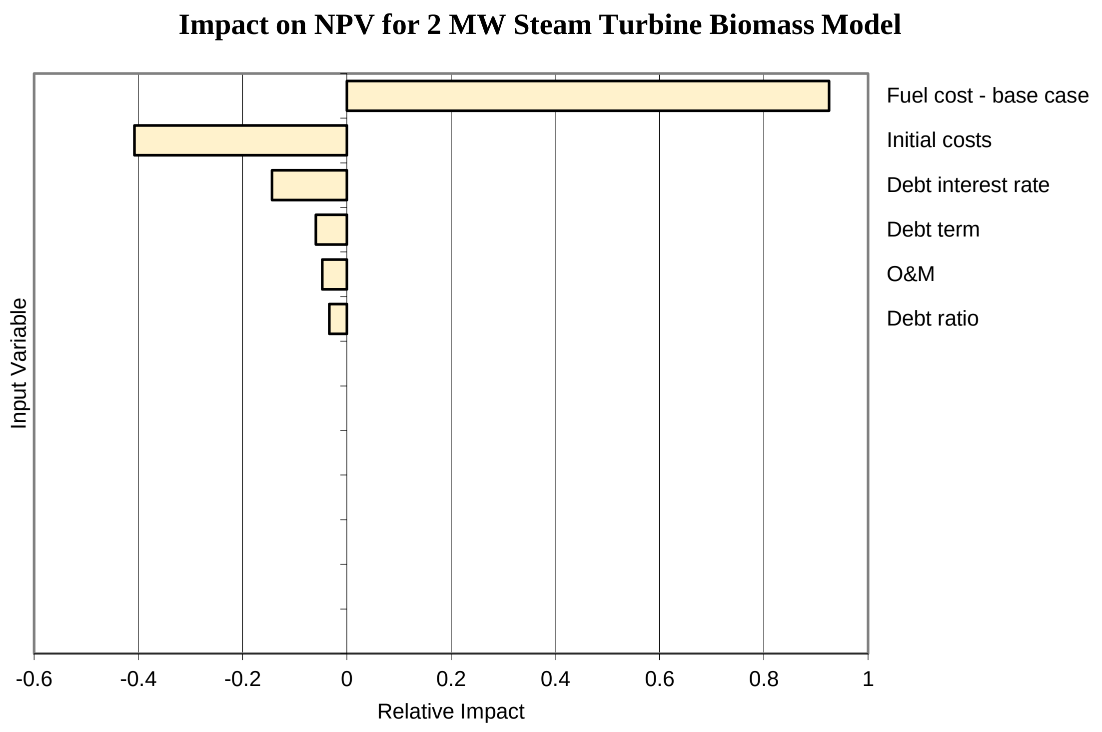


Figure A-23: Cumulative Cash-flow diagram for 2 MW Steam Turbine Biomass model



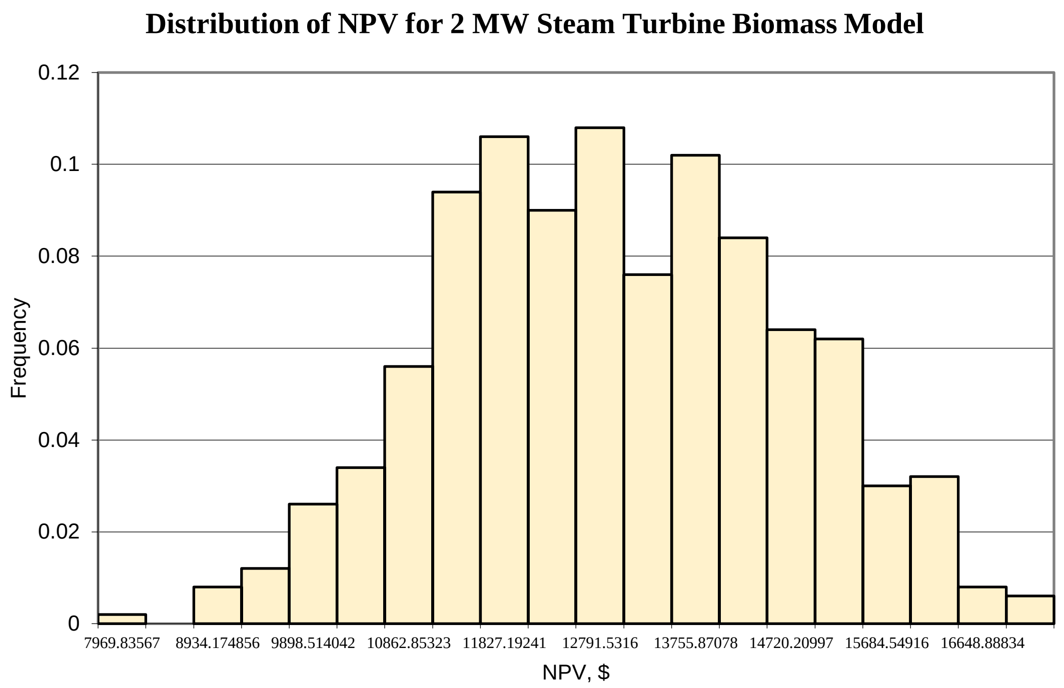


Figure A-24: Risk Analysis for 2 MW Steam turbine single cycle biomass model

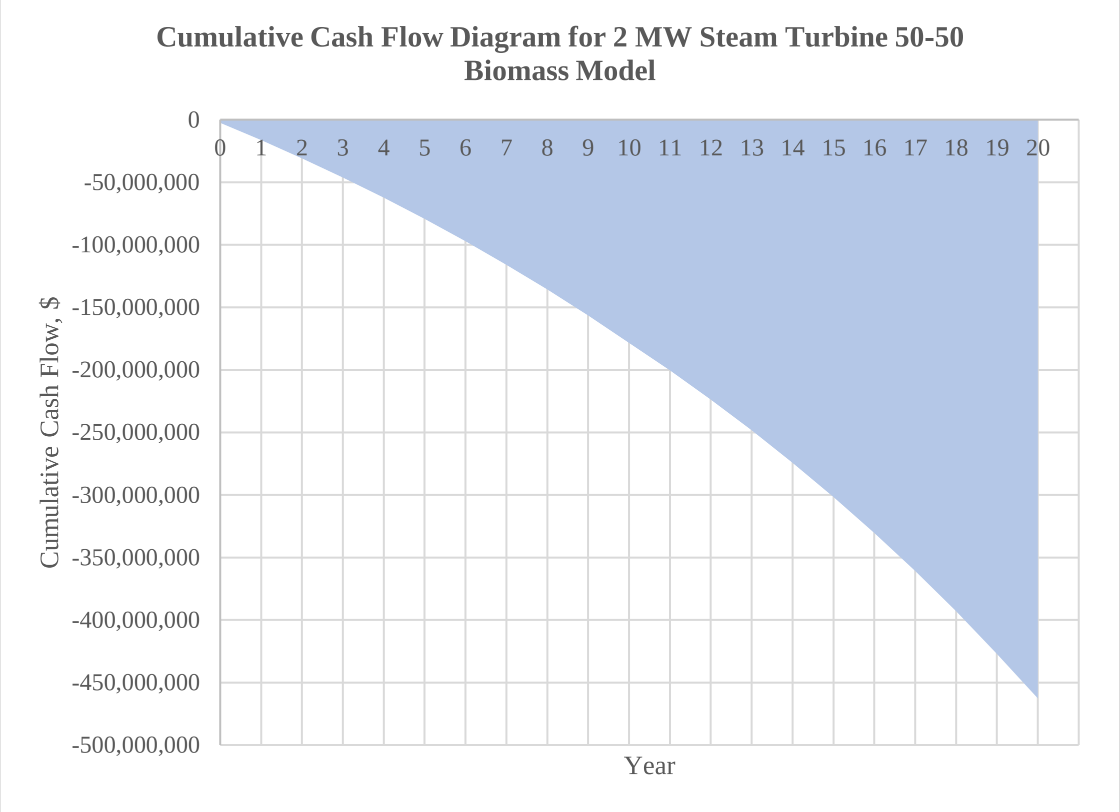
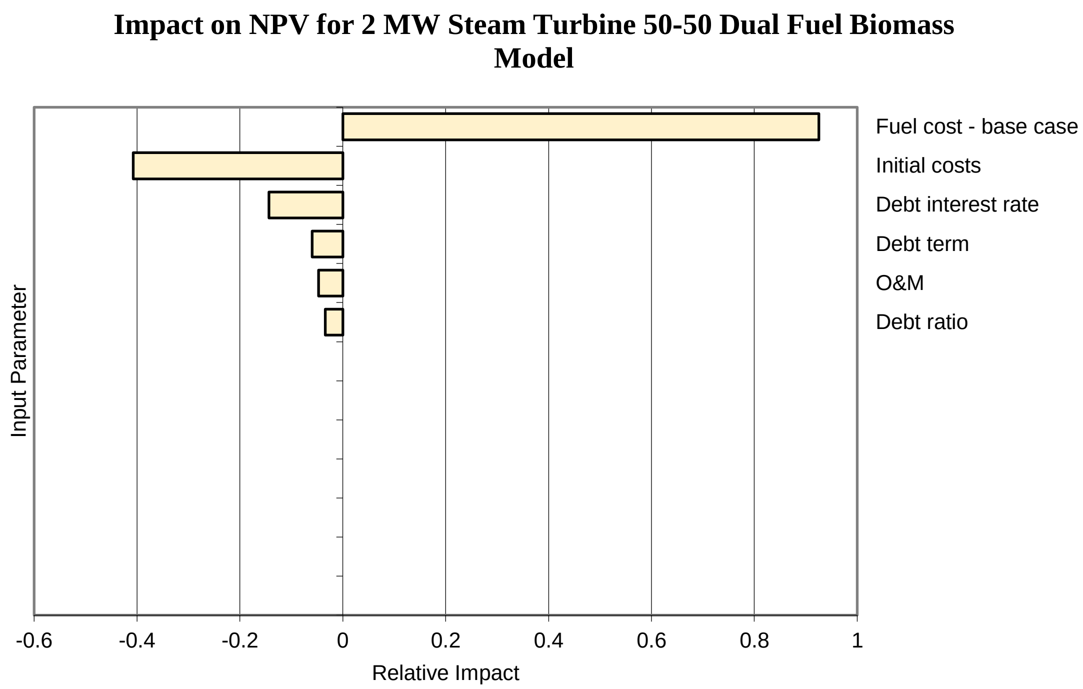


Figure A-25: Cumulative Cash-flow diagram for 2 MW Steam Turbine Biomass model having multifuel ratio 50-50 biomass-diesel



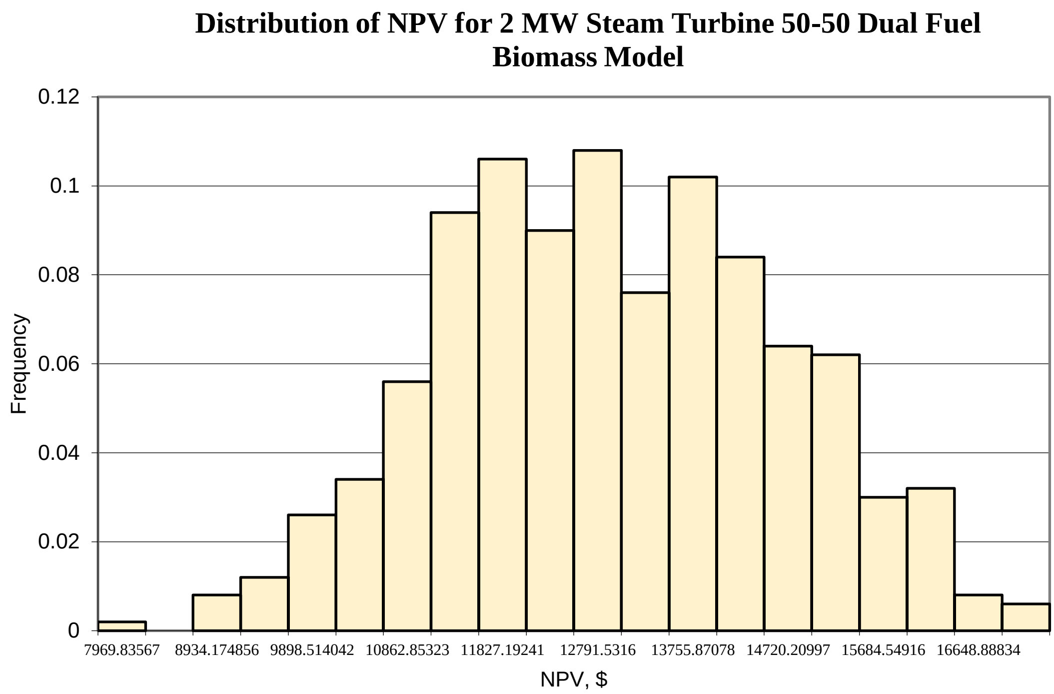


Figure A-26: Risk Analysis for 2 MW Steam turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel

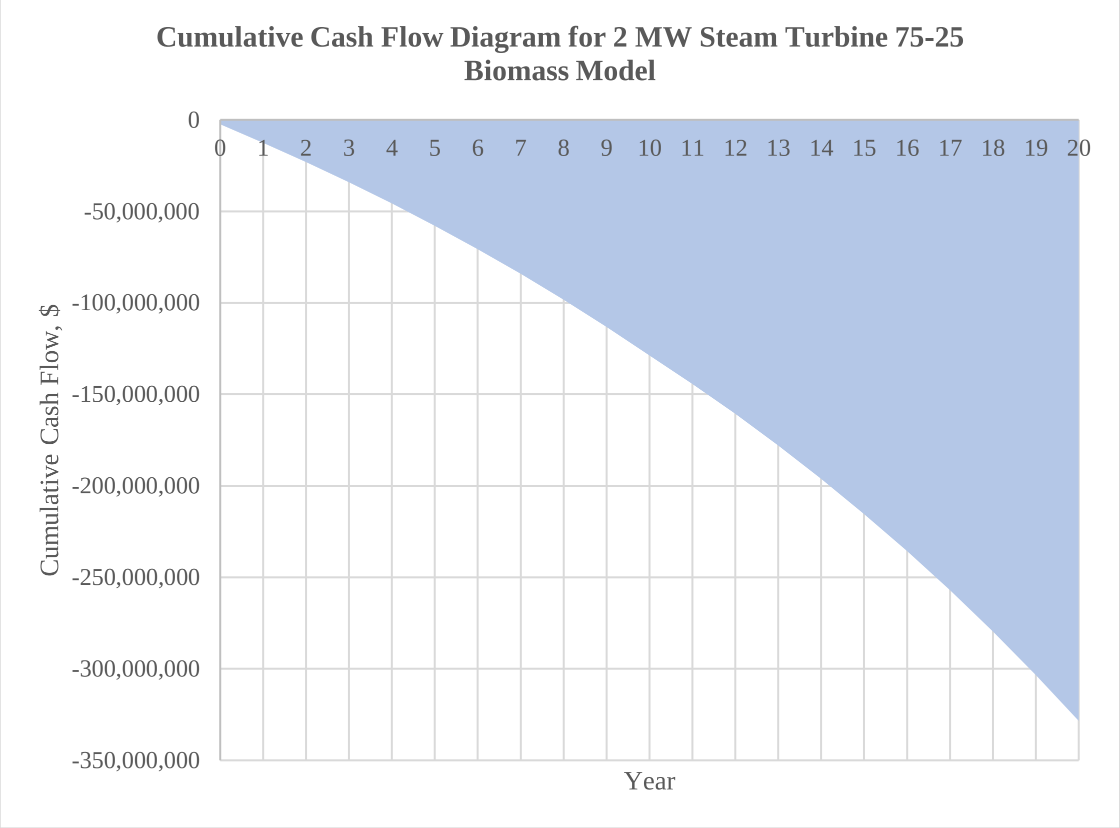
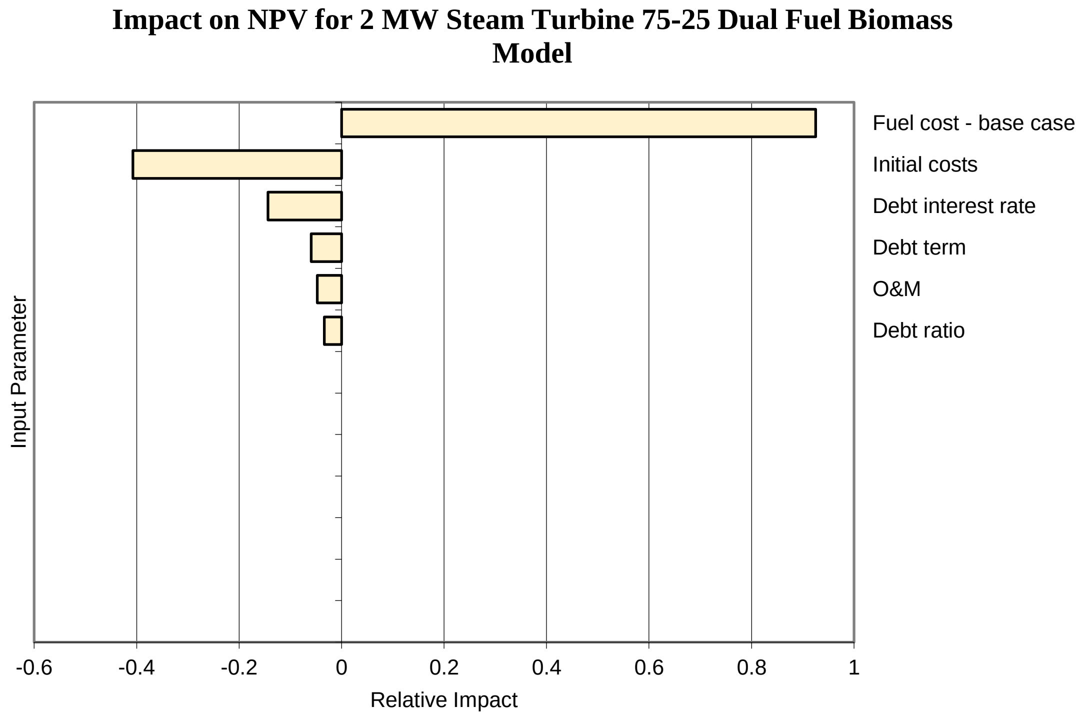


Figure A-27: Cumulative Cash-flow diagram for 2 MW Steam Turbine Biomass model having multifuel ratio 75-25 biomass-diesel



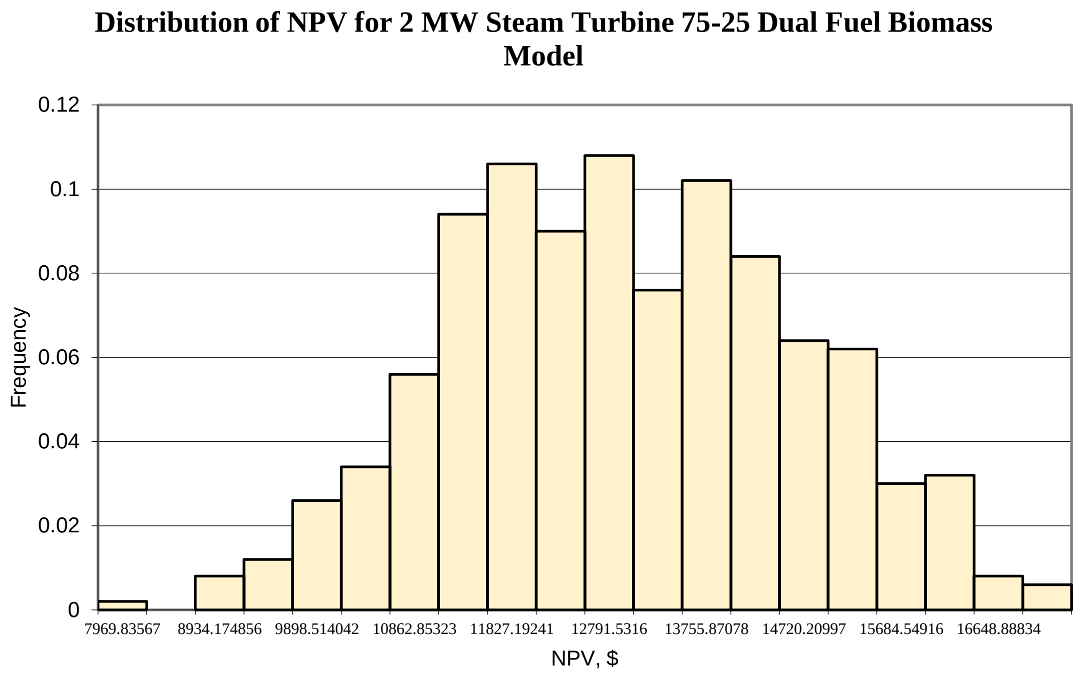


Figure A-28: Risk Analysis for 2 MW Steam turbine single cycle biomass model having multifuel ratio 75-25 biomass-diesel

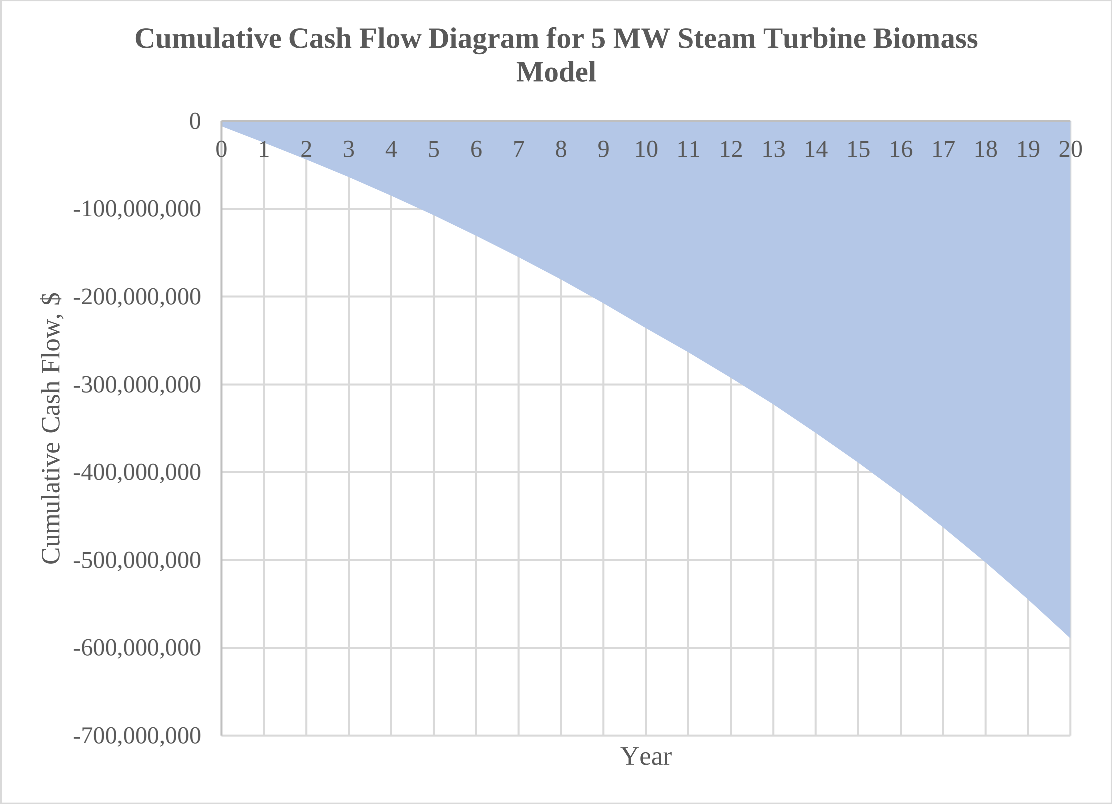
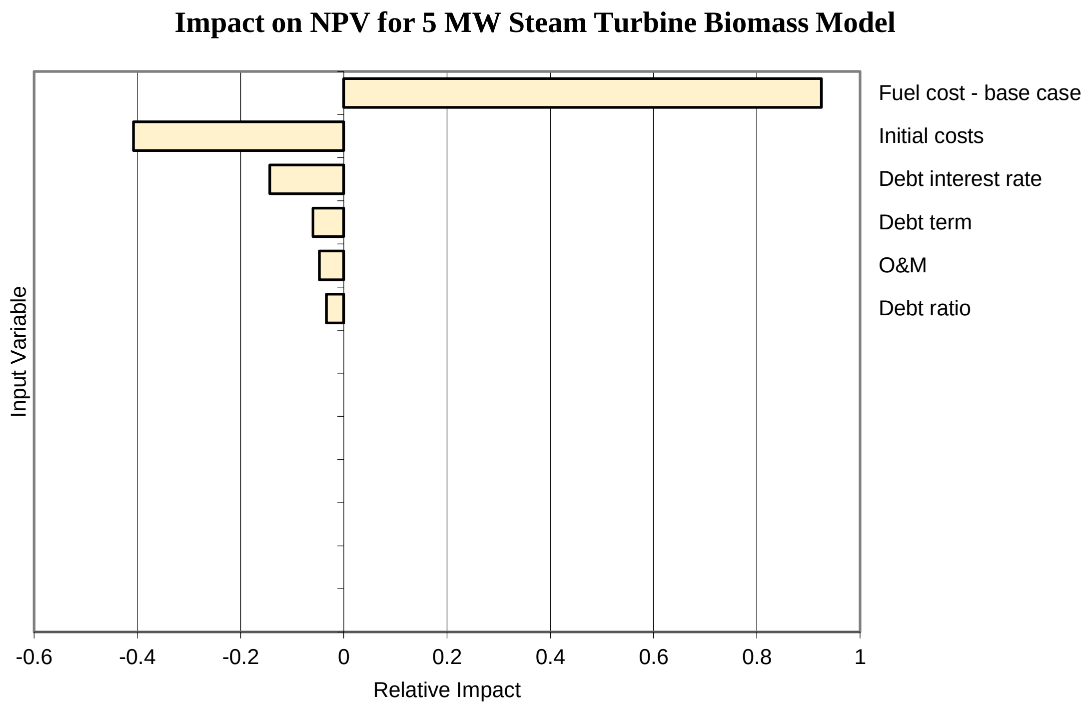


Figure A-29: Cumulative Cash-flow diagram for 5 MW Steam Turbine Biomass model



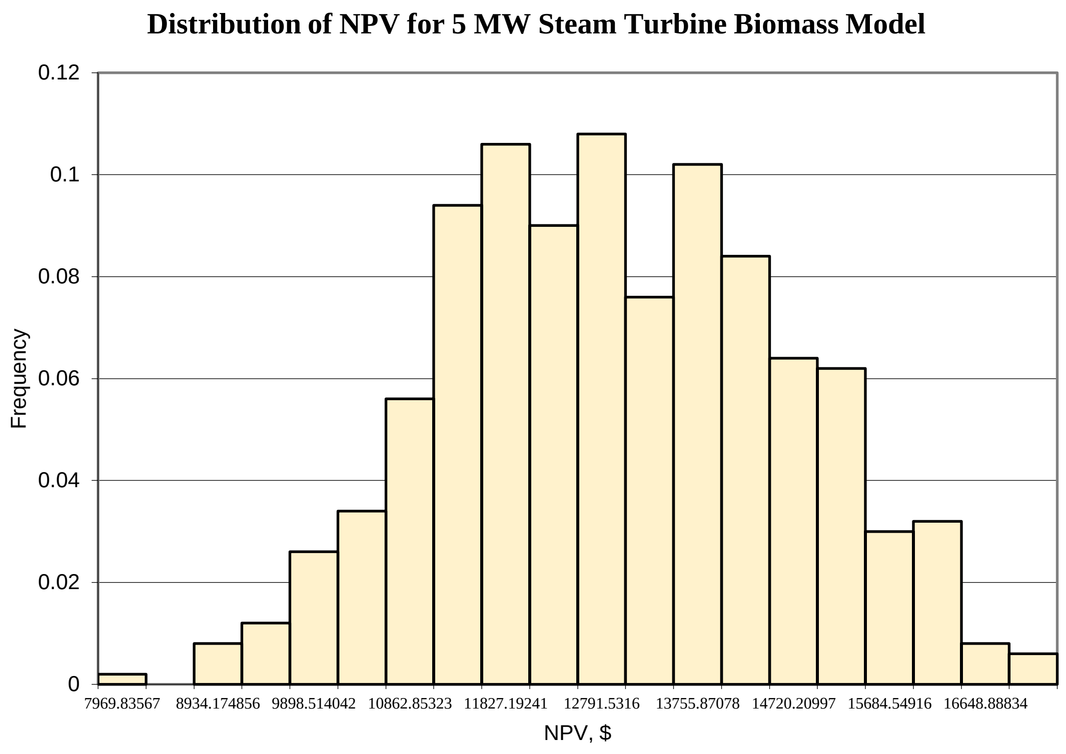


Figure A-30: Risk Analysis for 5 MW Steam turbine single cycle biomass

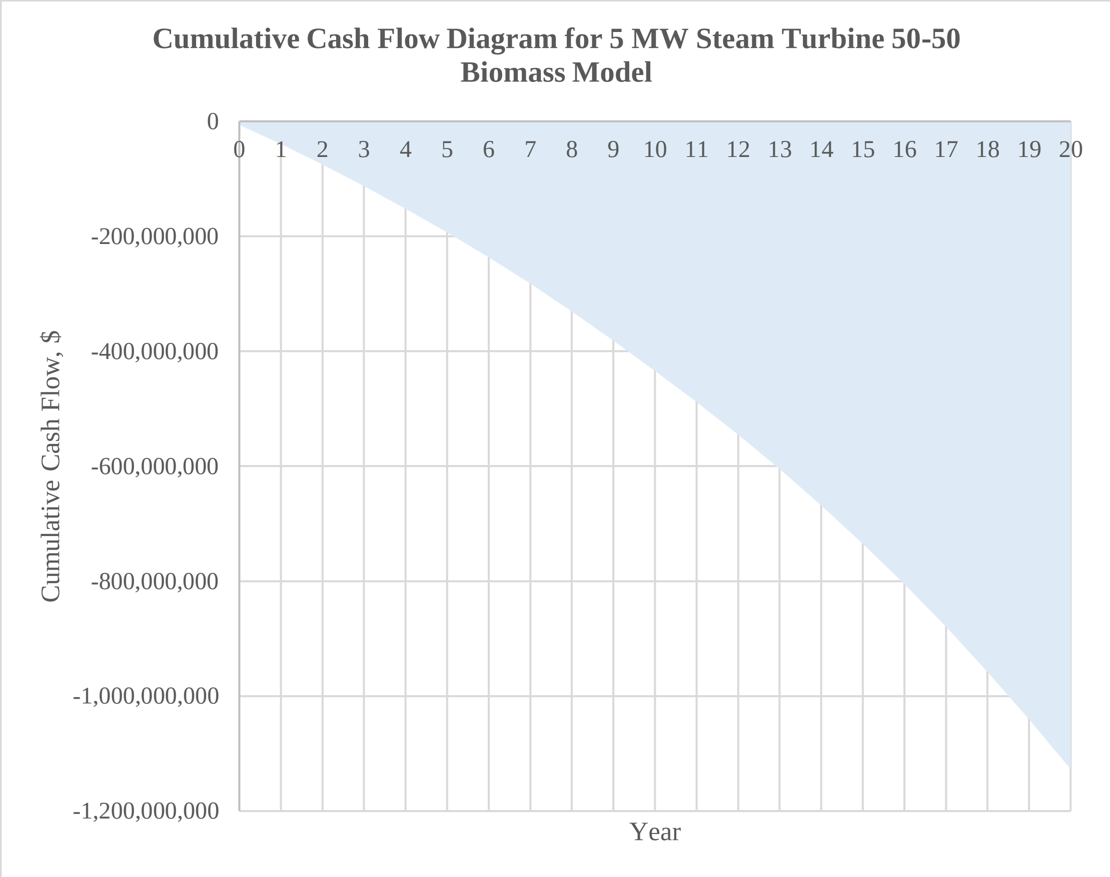
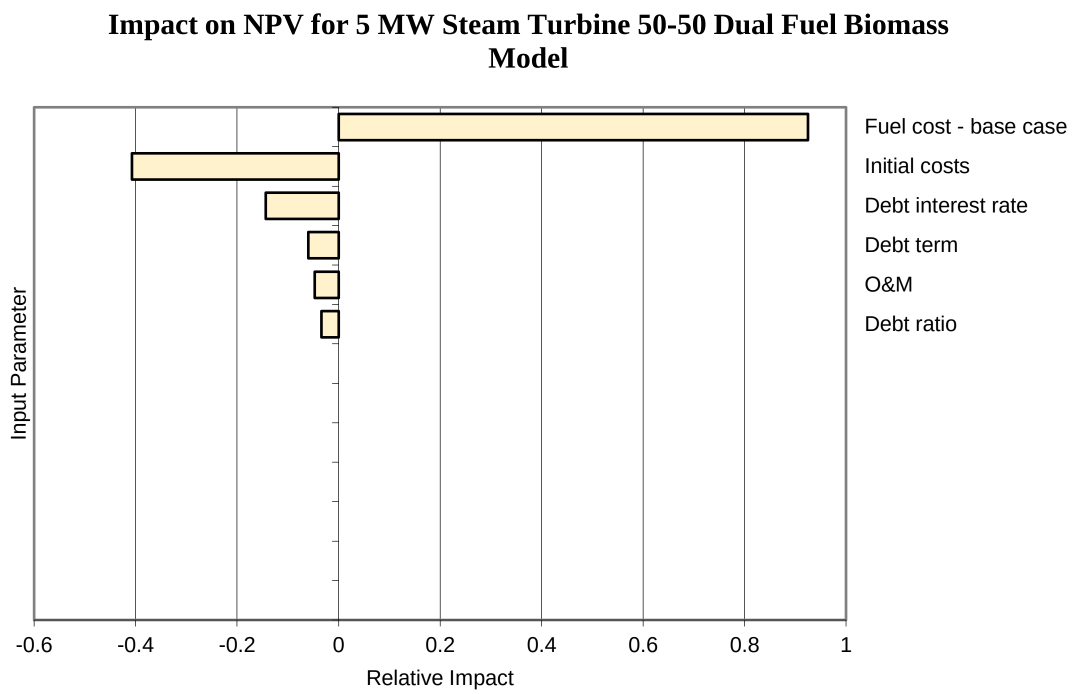


Figure A-31: Cumulative Cash-flow diagram for 5 MW Steam Turbine Biomass model having multifuel ratio 50-50 biomass-diesel



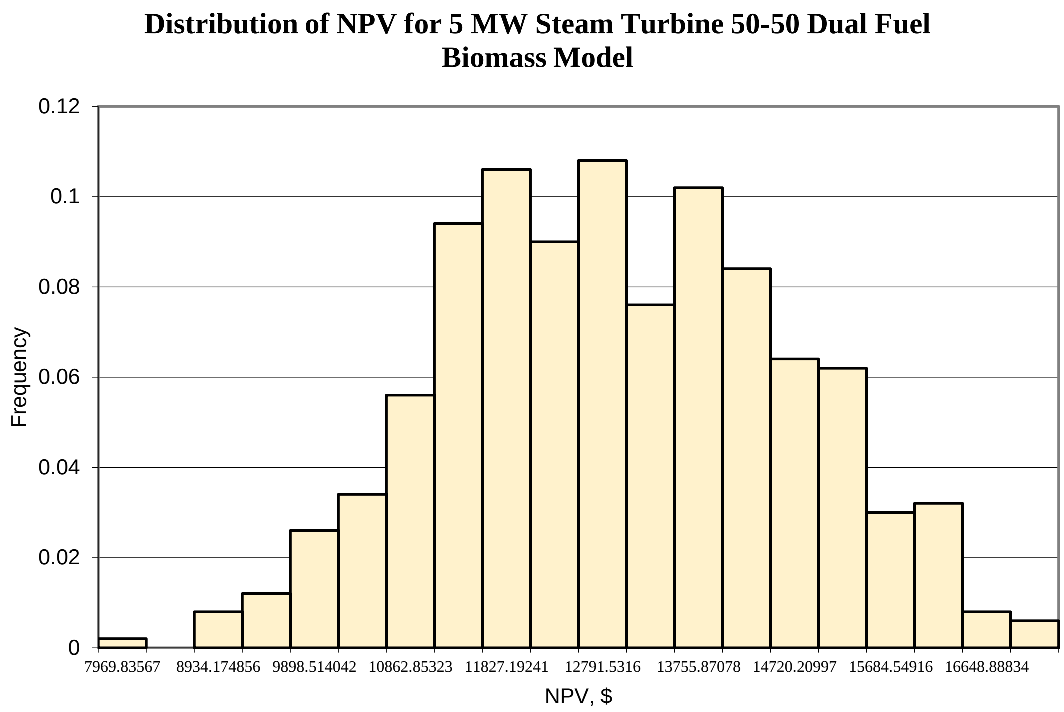


Figure A-32: Risk Analysis for 5 MW Steam turbine single cycle biomass model having multifuel ratio 50-50 biomass-diesel

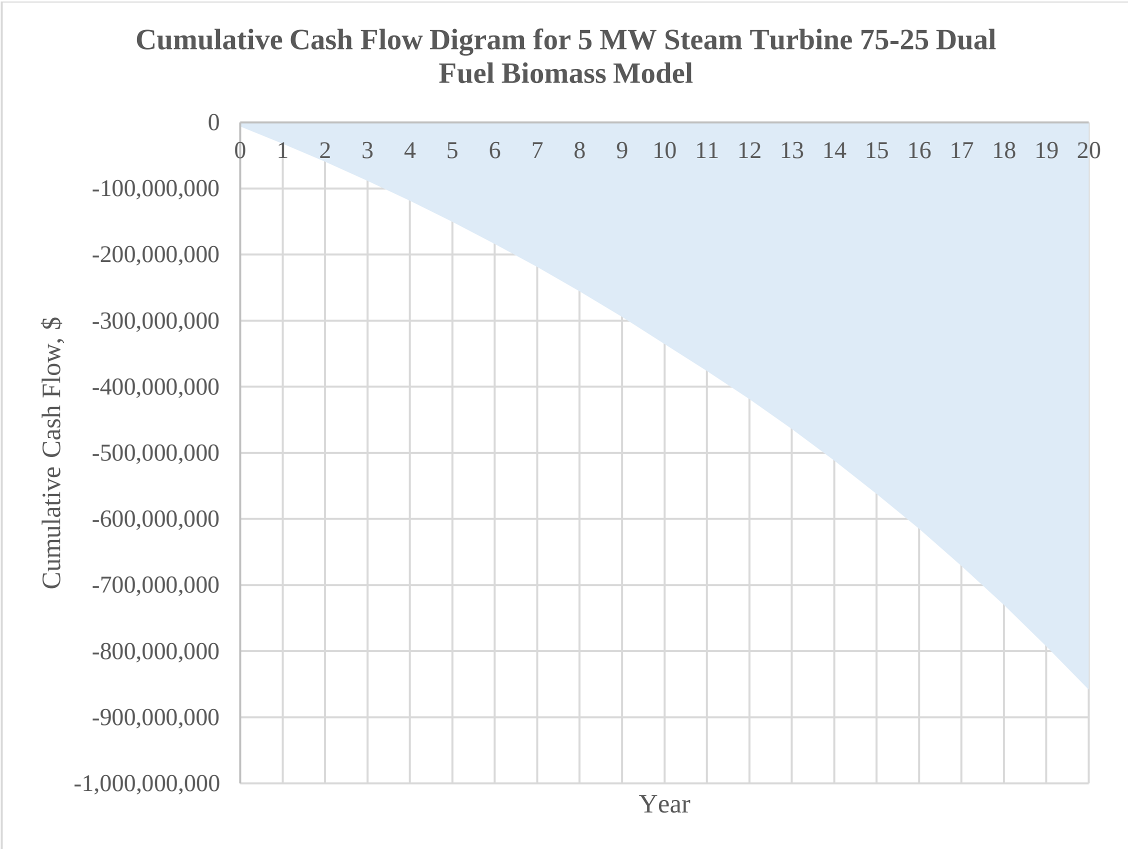
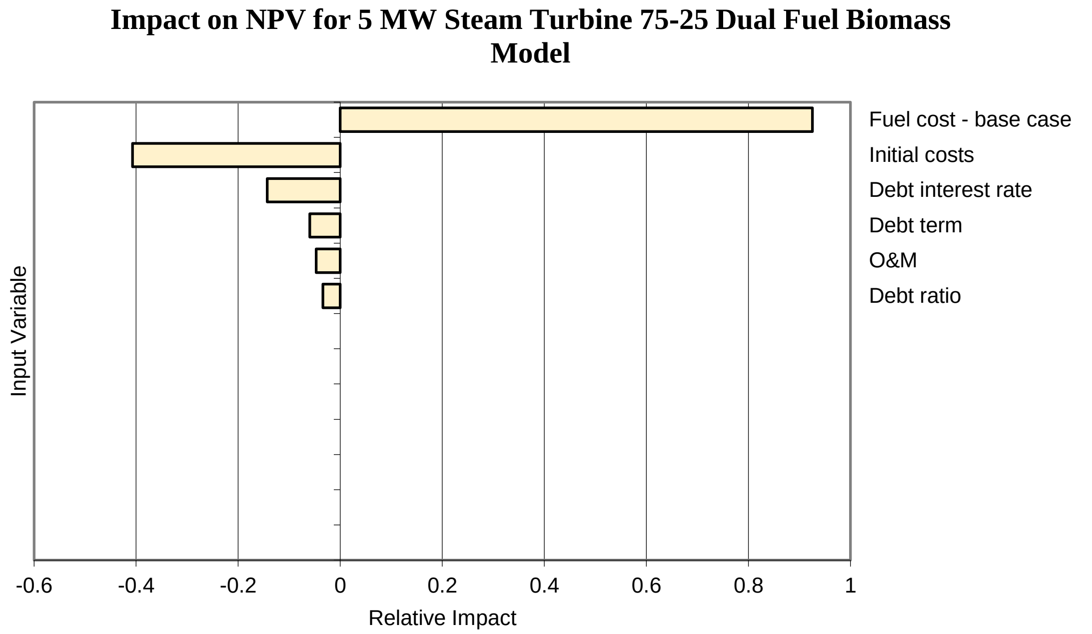


Figure A-33: Cumulative Cash-flow diagram for 5 MW Steam Turbine Biomass model having multifuel ratio 75-25 biomass-diesel



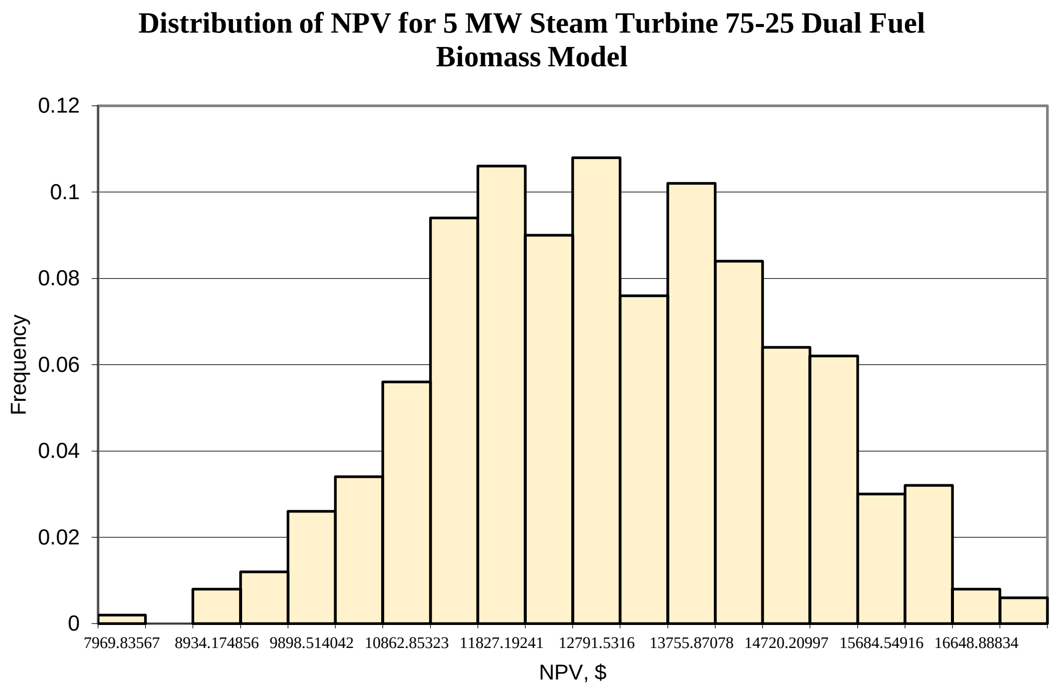


Figure A-34: Risk Analysis for 5 MW Steam turbine single cycle biomass model having multifuel ratio 75-25 biomass-diesel

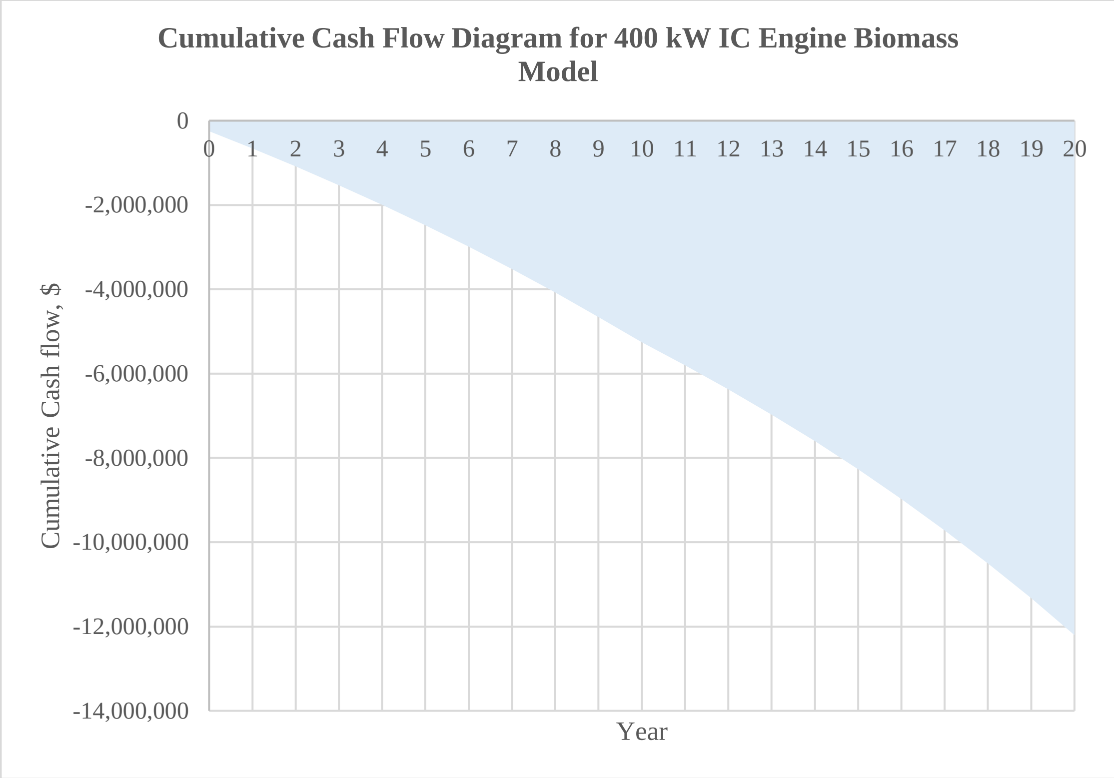
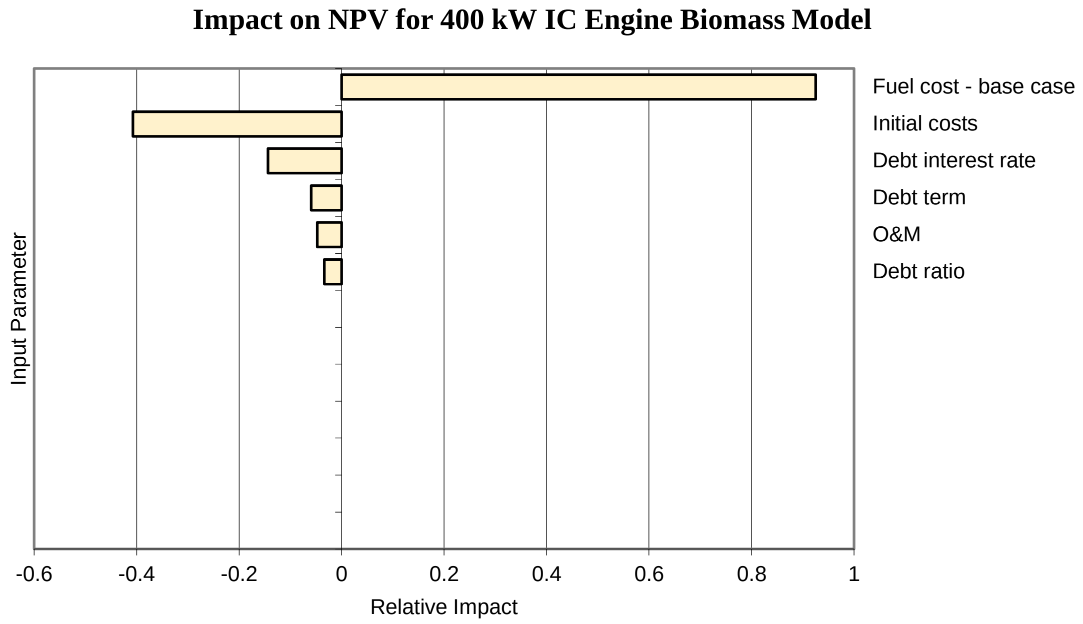


Figure A-35: Cumulative Cash-flow diagram for 400 kW IC Engine Biomass model



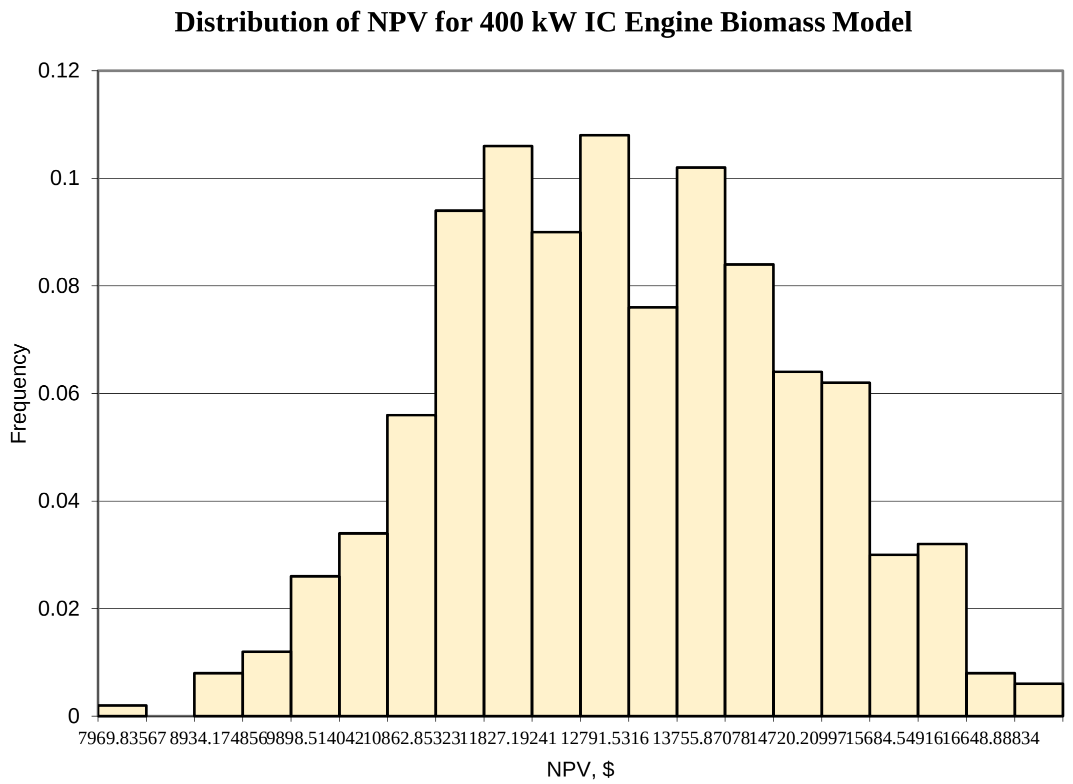


Figure A-36: Risk Analysis for 400 kW IC Engine biomass model

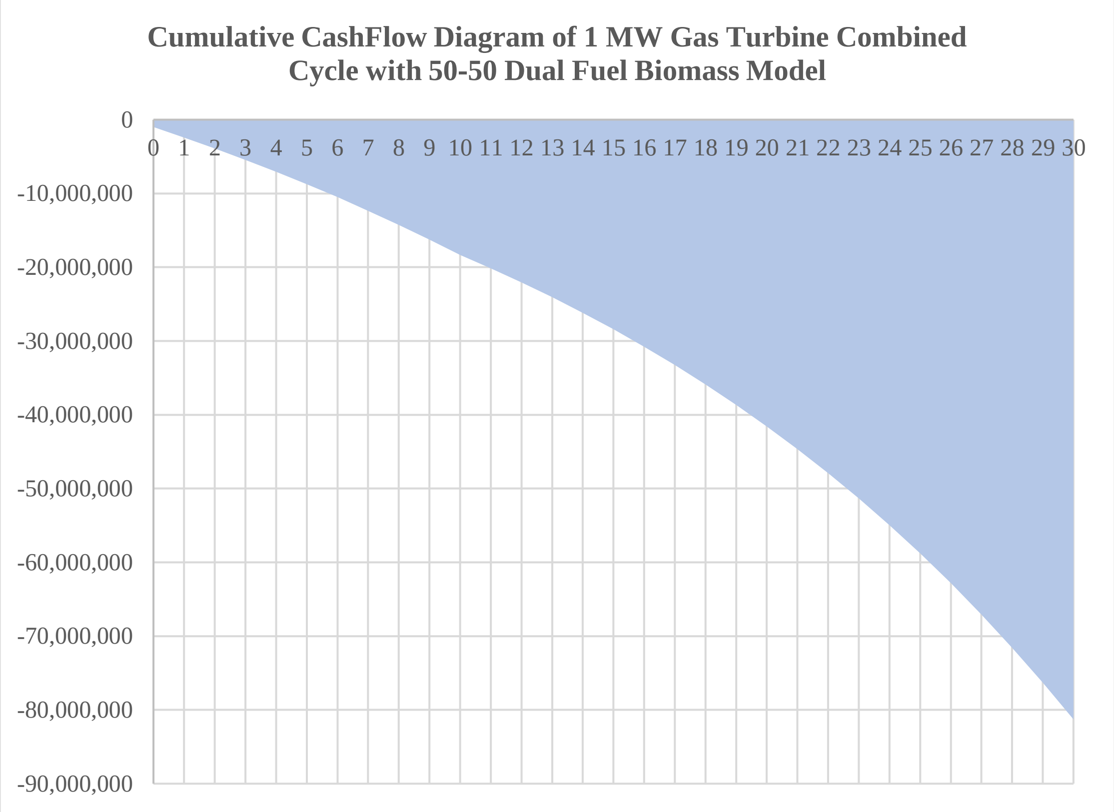
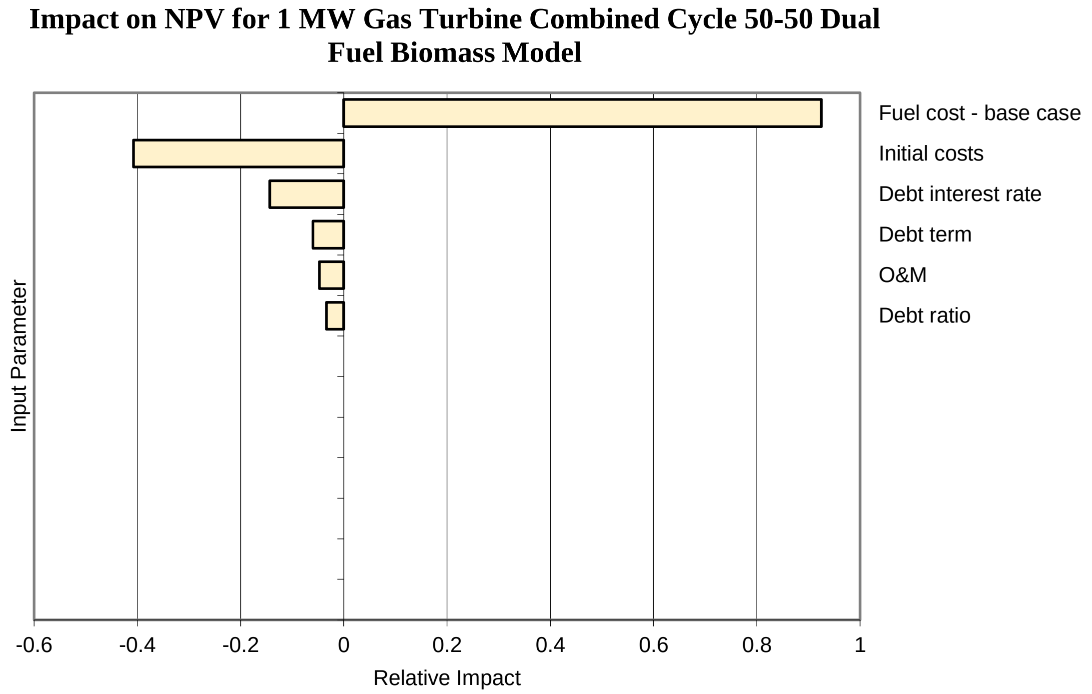


Figure A-37: Cumulative Cash-flow diagram for 1 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 50-50 biomass-diesel



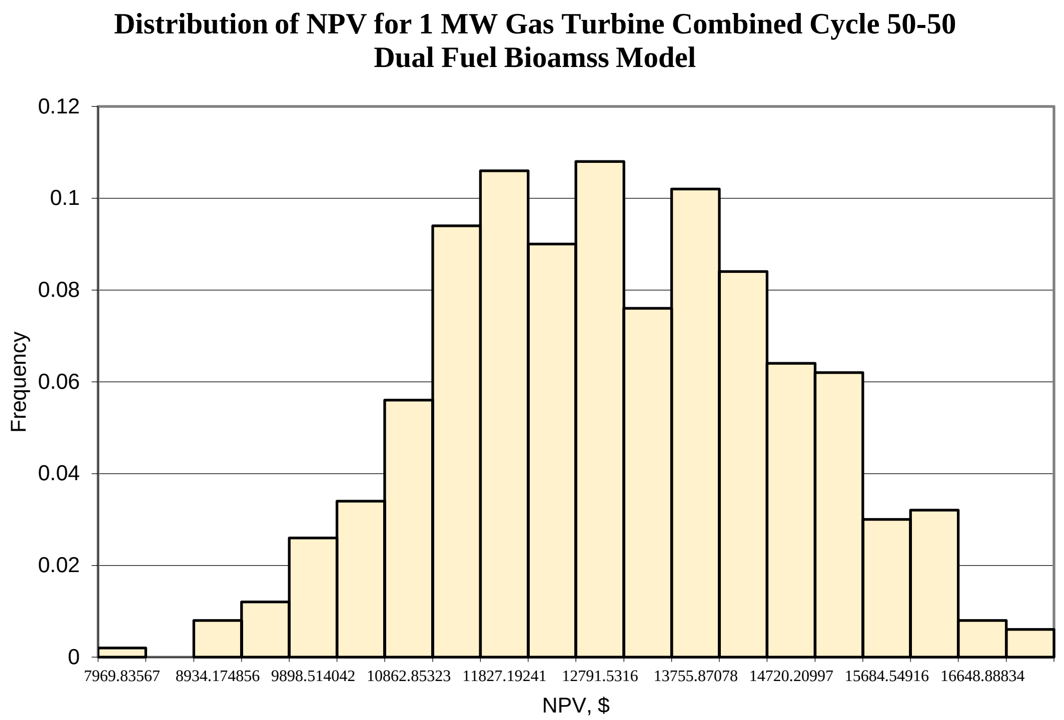


Figure A-38: Risk Analysis for 1 MW Gas turbine combined cycle biomass model having multifuel ratio 50-50 biomass-diesel

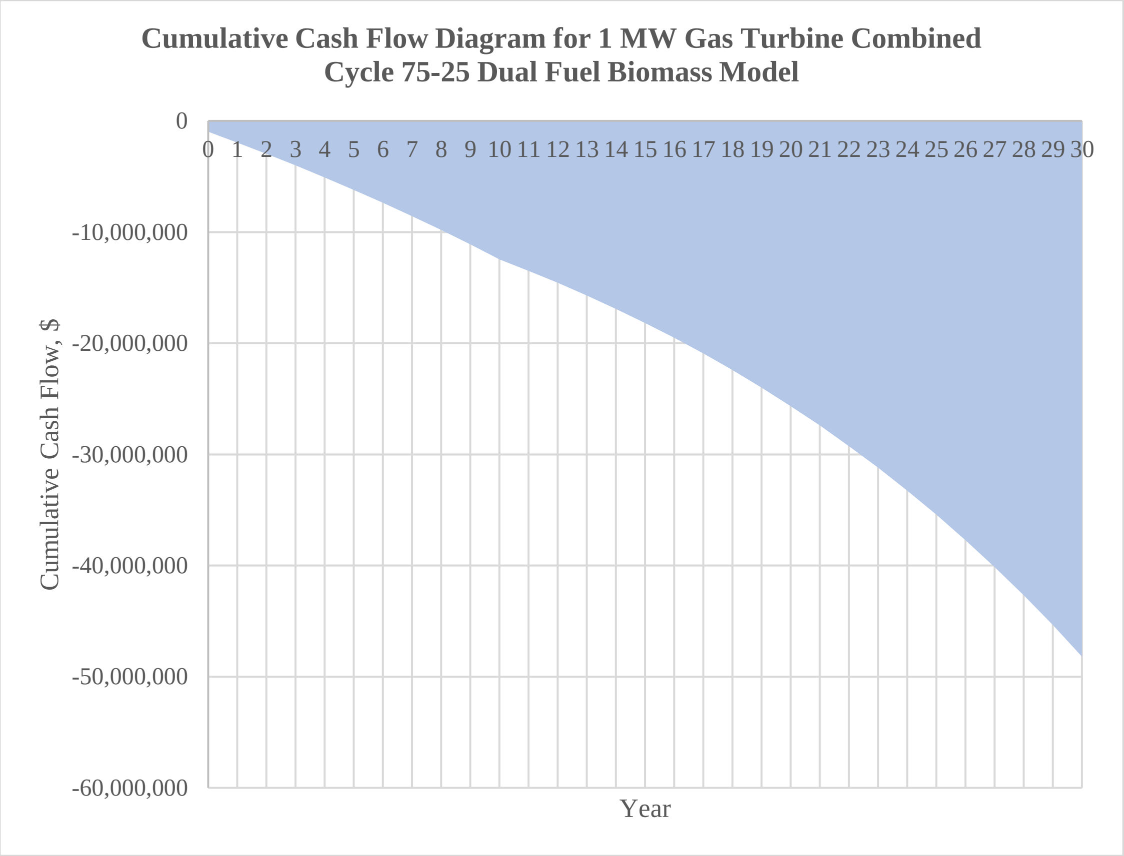
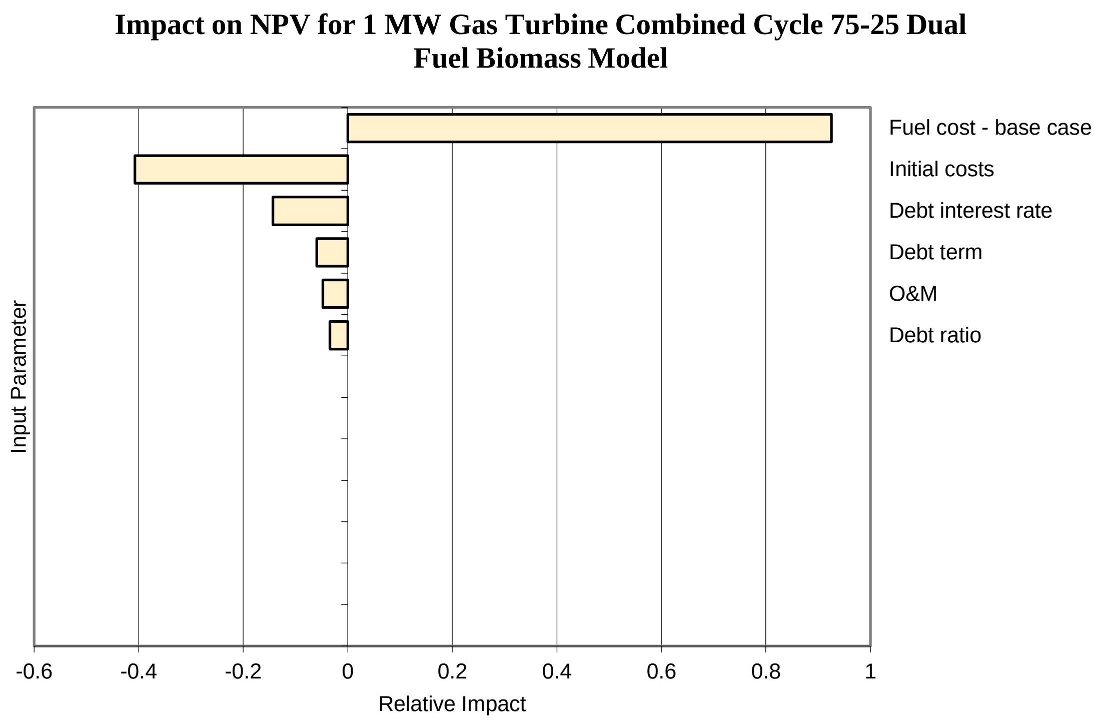


Figure A-39: Cumulative Cash-flow diagram for 1 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 75-25 biomass-diesel



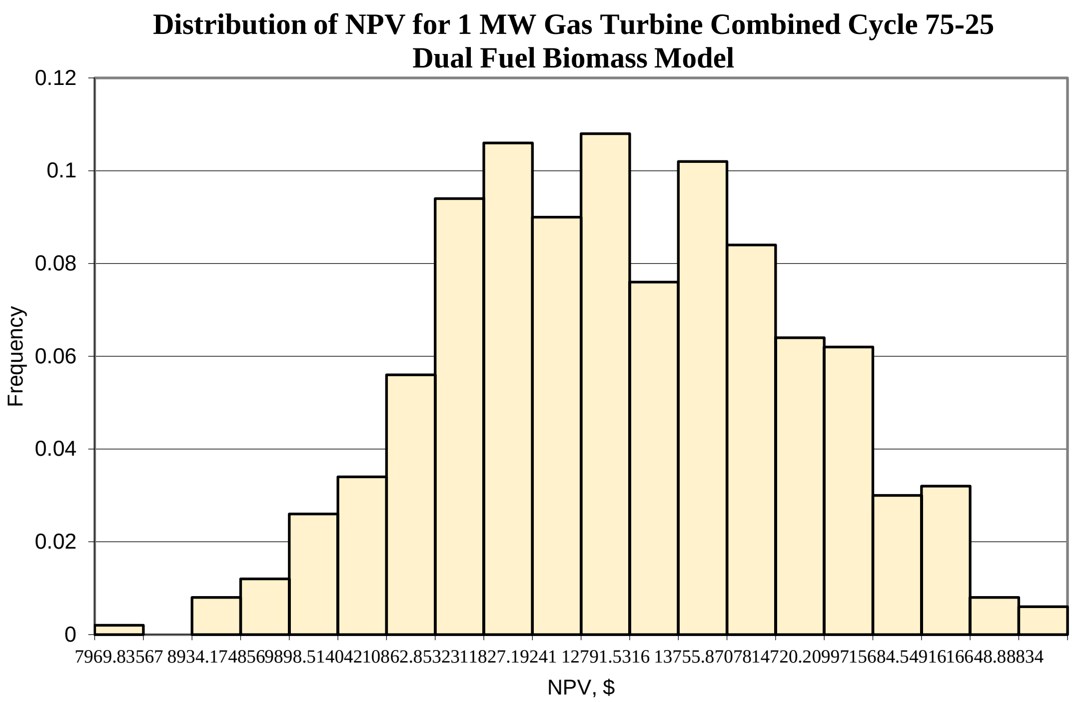


Figure A-40: Risk Analysis for 1 MW Gas turbine combined cycle biomass model having multifuel ratio 75-25 biomass-diesel

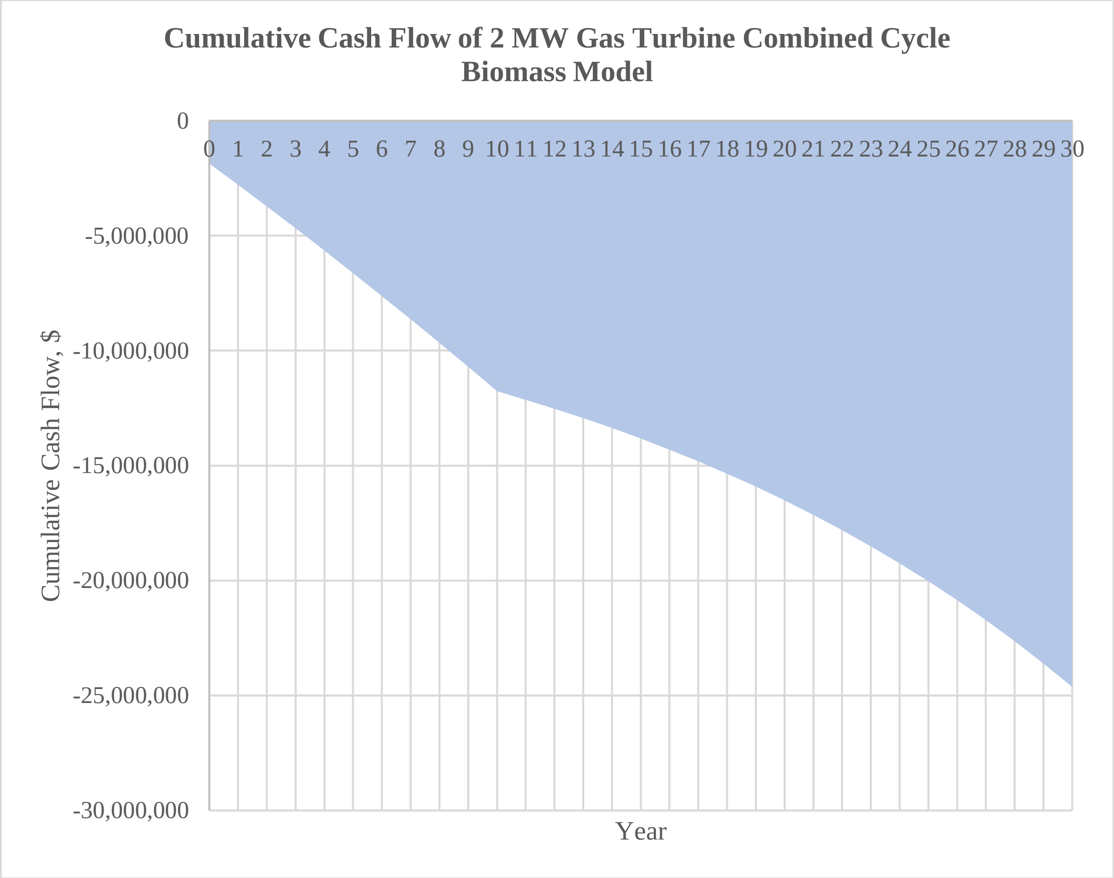
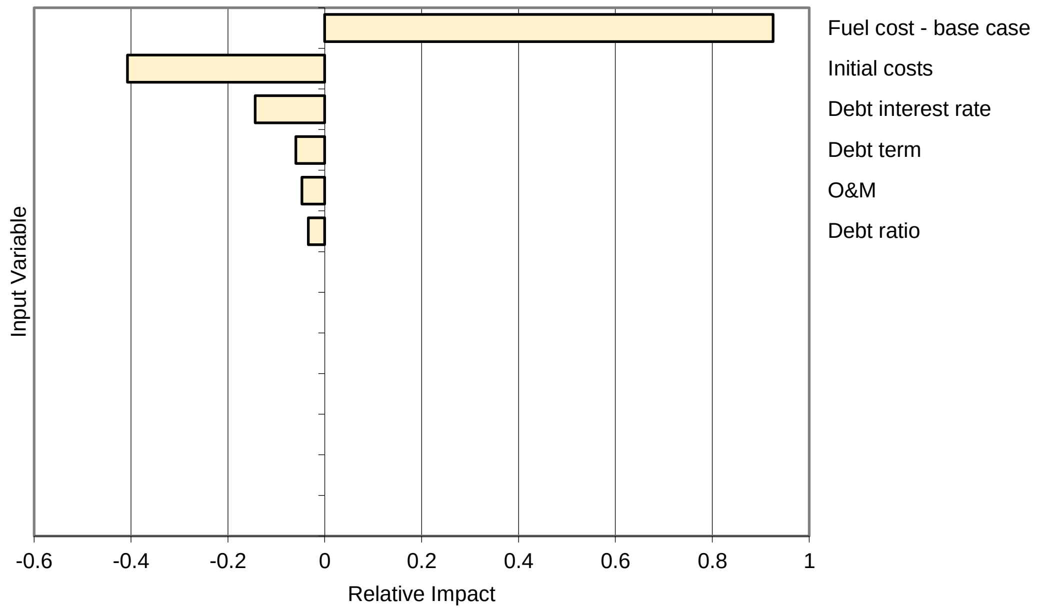


Figure A-41: Cumulative Cash-flow diagram for 2 MW Gas turbine Combined Cycle Biomass model

Impact on NPV for 2 MW Gas Turbine Combined Cycle Biomass Model



Distribution of NPV for 2 MW Gas Turbine Combined Cycle Biomass Model

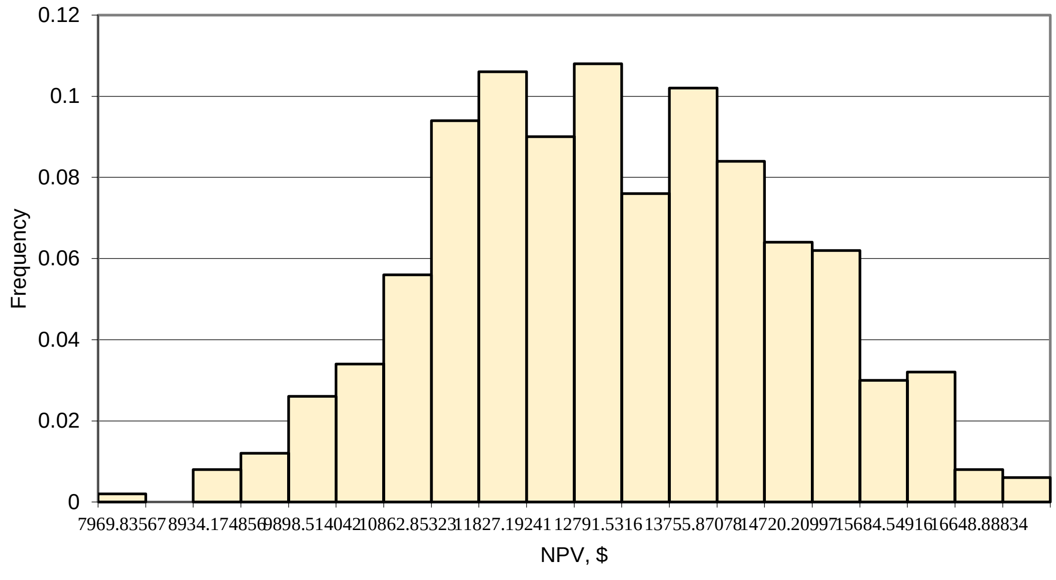


Figure A-42: Risk Analysis for 2 MW Gas turbine combined cycle biomass model

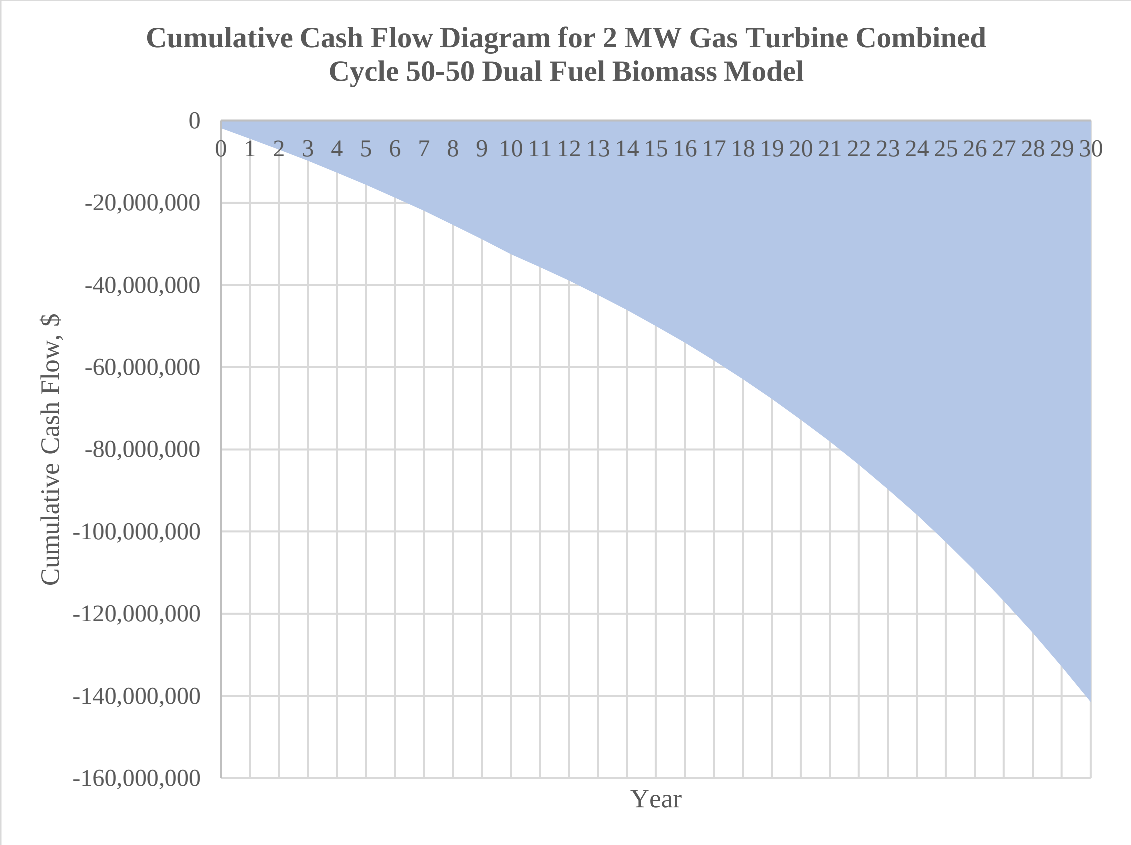
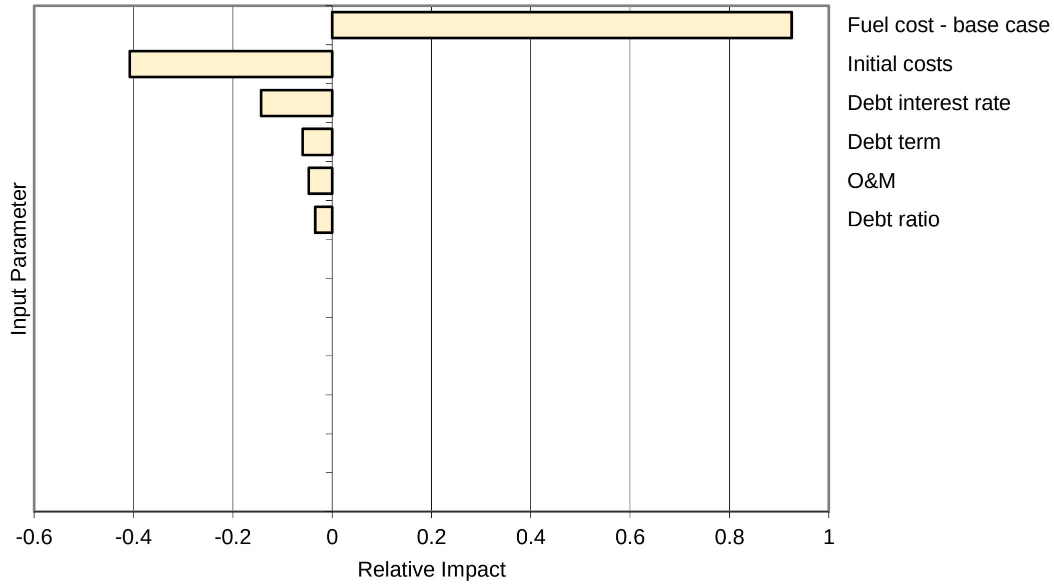


Figure A-43: Cumulative Cash-flow diagram for 2 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 50-50 biomass-diesel

Impact on NPV for 2 MW Gas Turbine Combined Cycle 50-50 Dual Fuel Biomass Model



Distribution of NPV for 2 MW Gas Turbine Combined Cycle 50-50 Dual Fuel Biomass Model

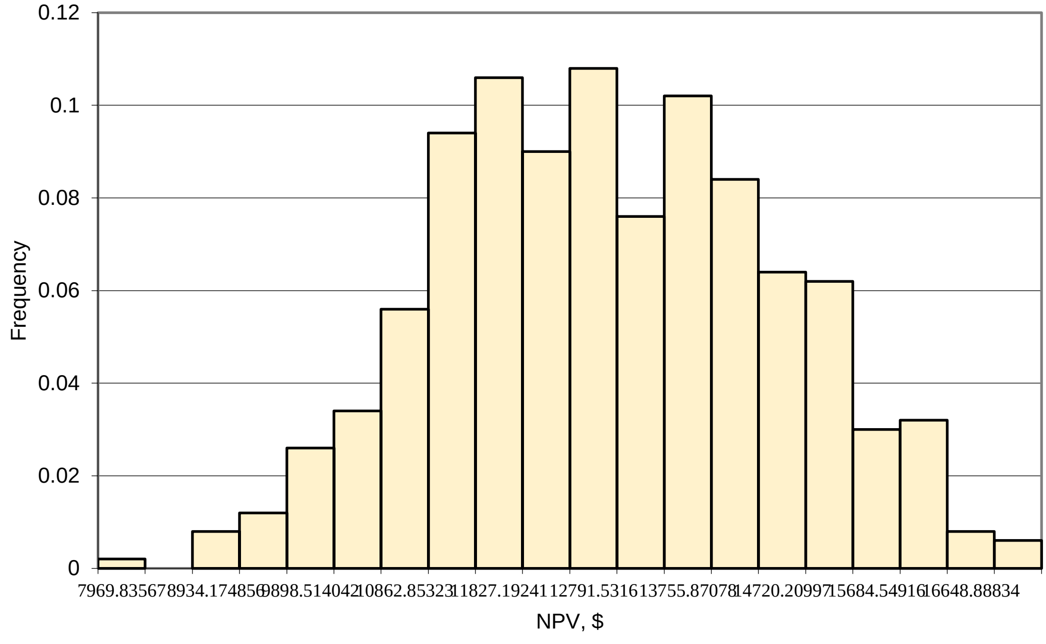


Figure A-44: Risk Analysis for 2 MW Gas turbine combined cycle biomass model having multifuel ratio 50-50 biomass-diesel

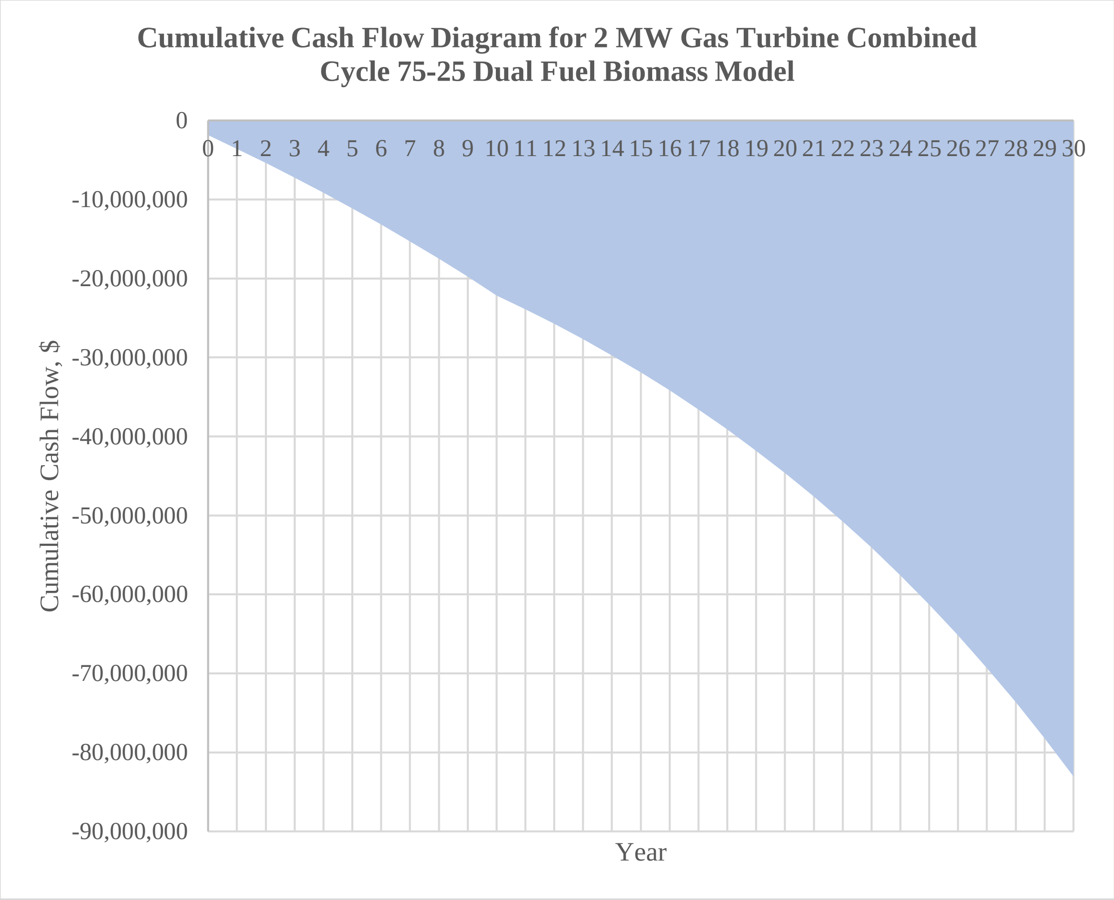
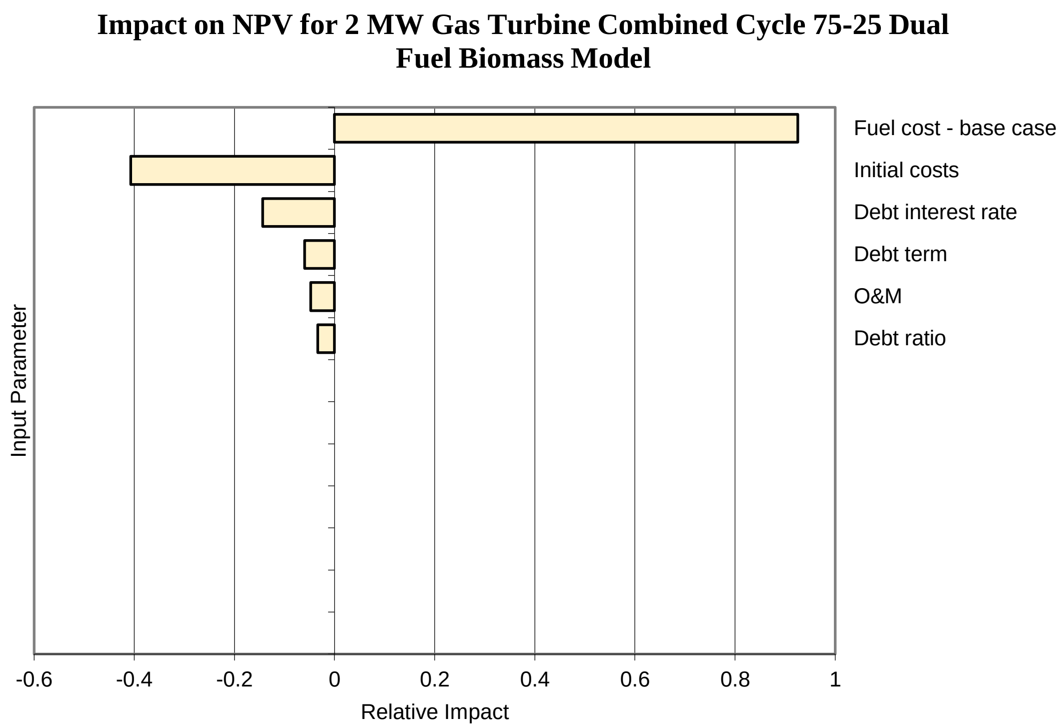


Figure A-45: Cumulative Cash-flow diagram for 2 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 75-25 biomass-diesel



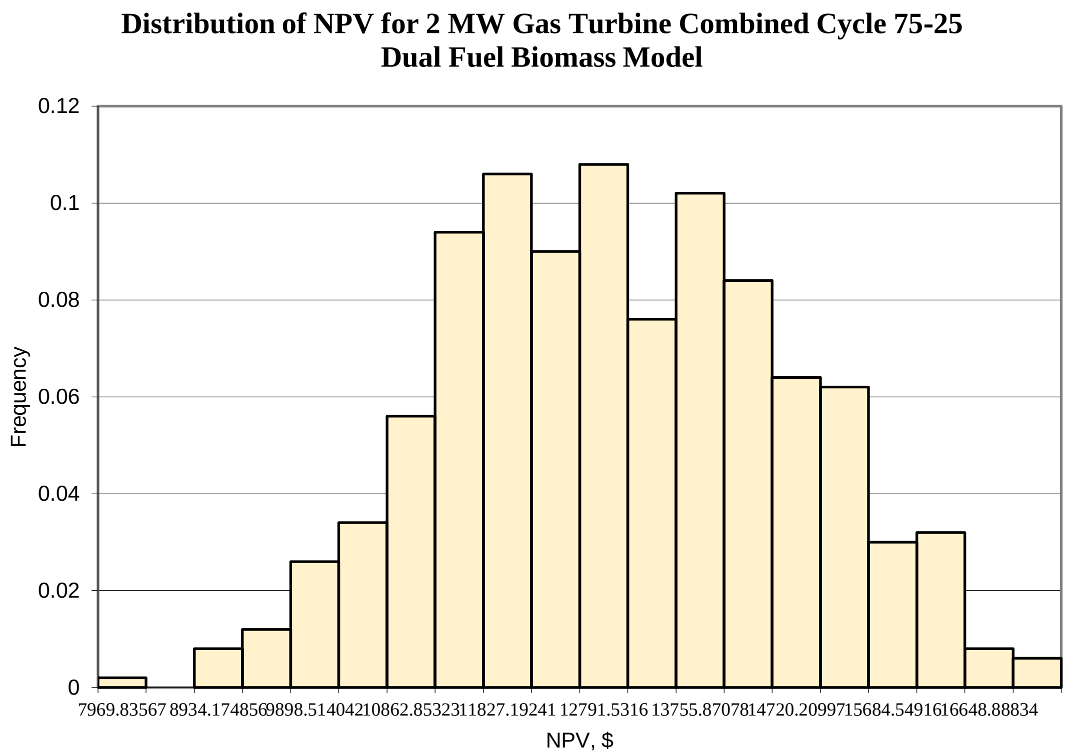


Figure A-46: Risk Analysis for 2 MW Gas turbine combined cycle biomass model having multifuel ratio 75-25 biomass-diesel

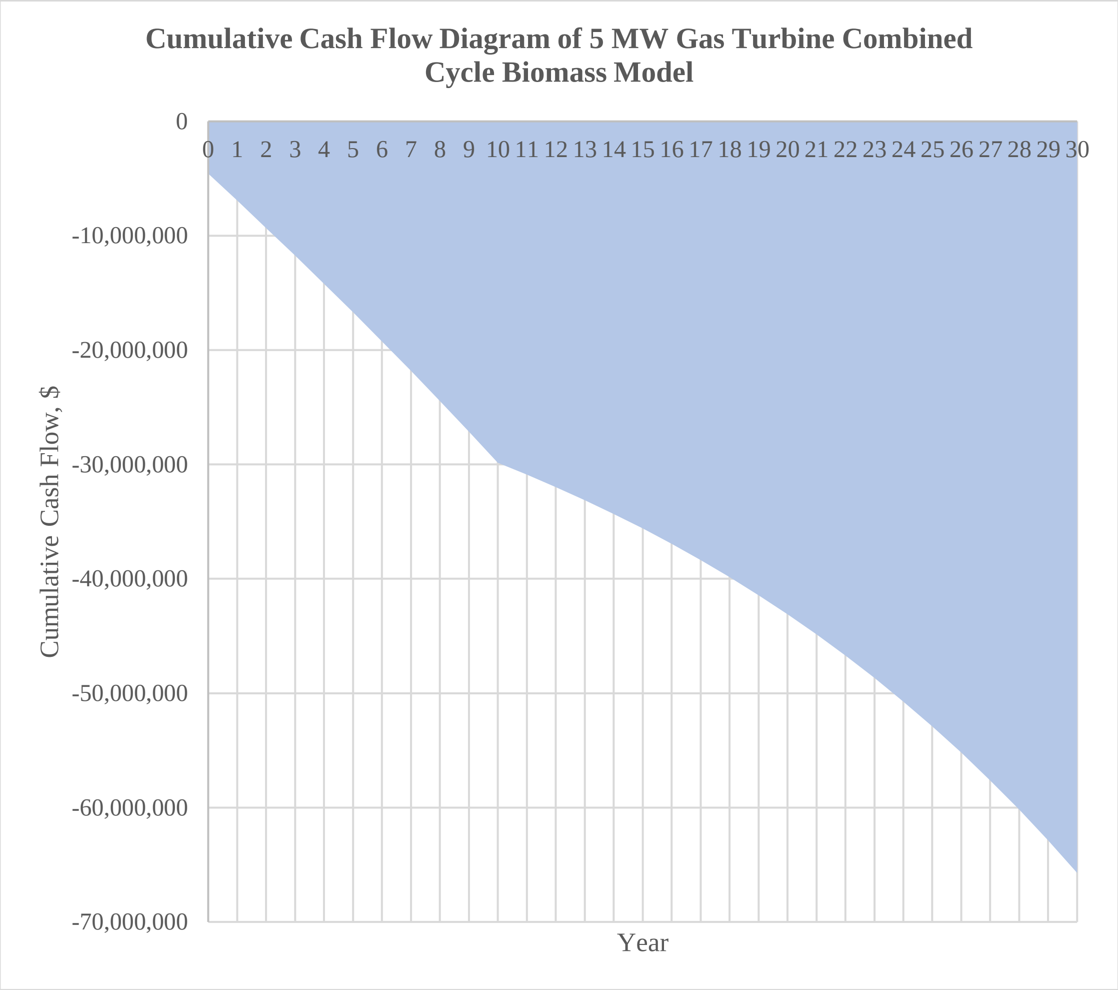
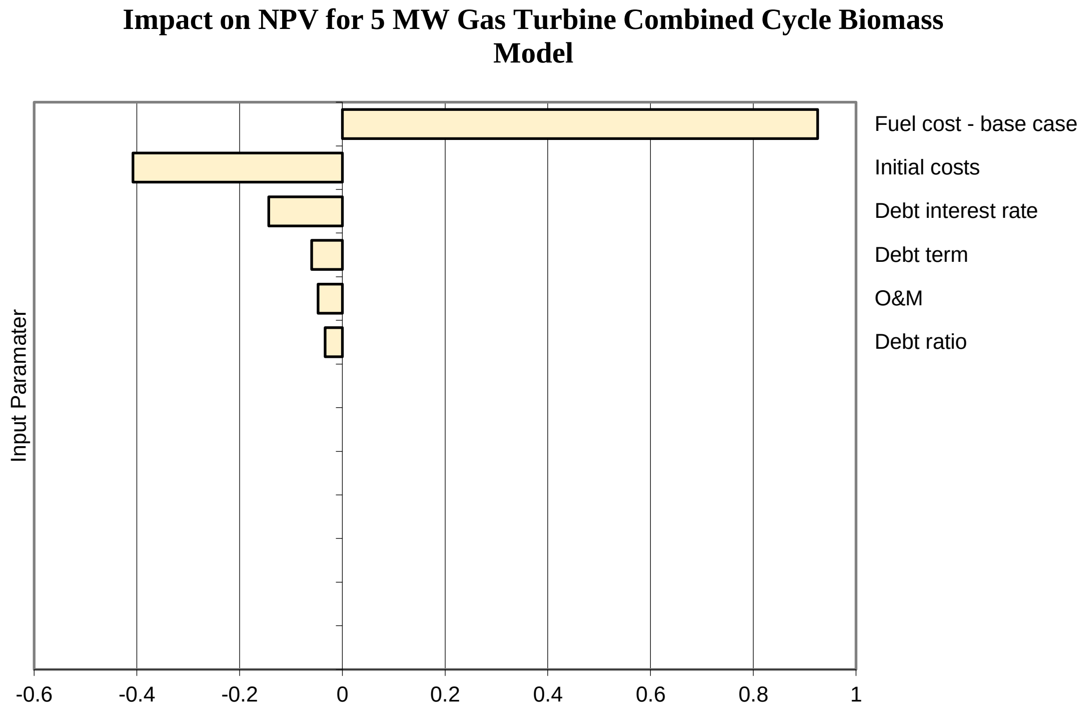


Figure A-47: Cumulative Cash-flow diagram for 5 MW Gas turbine Combined Cycle Biomass model



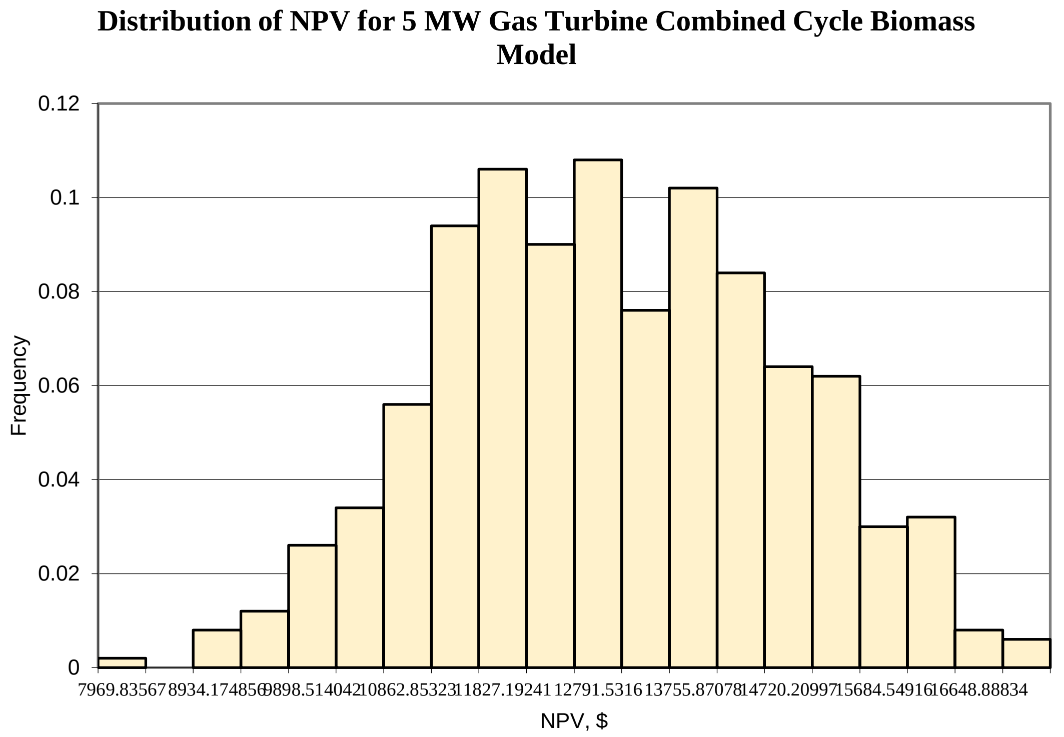


Figure A-48: Risk Analysis for 5 MW Gas turbine combined cycle biomass model

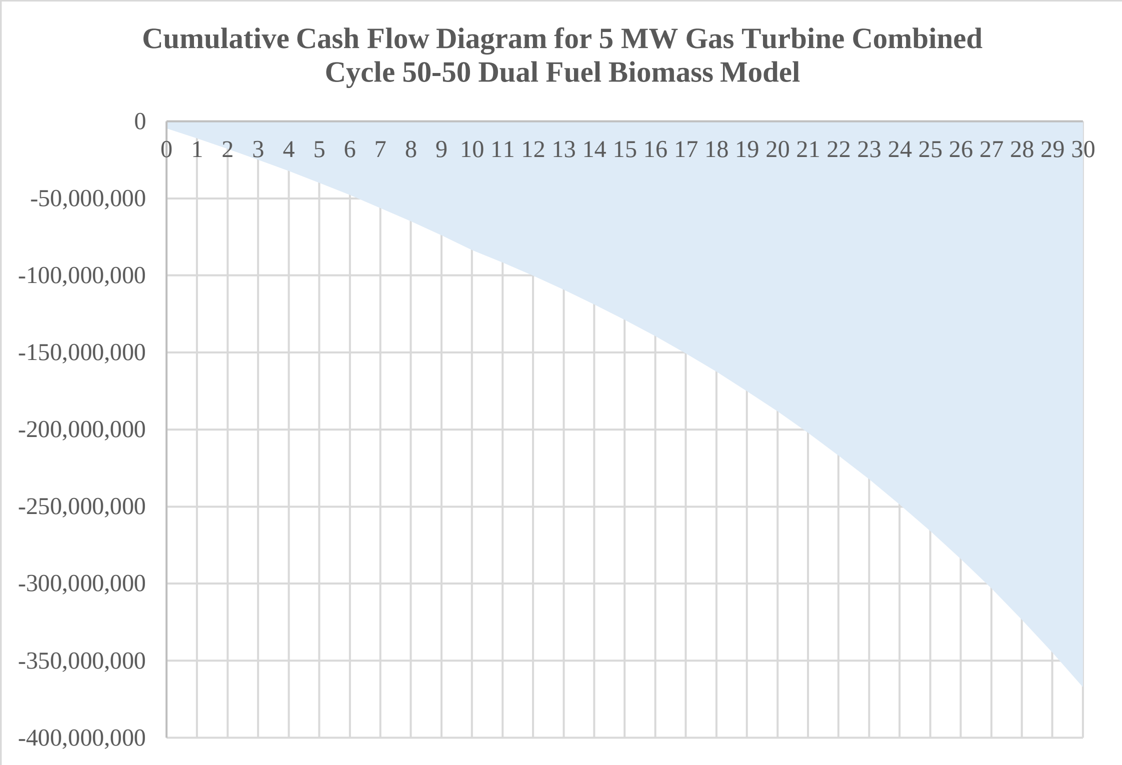
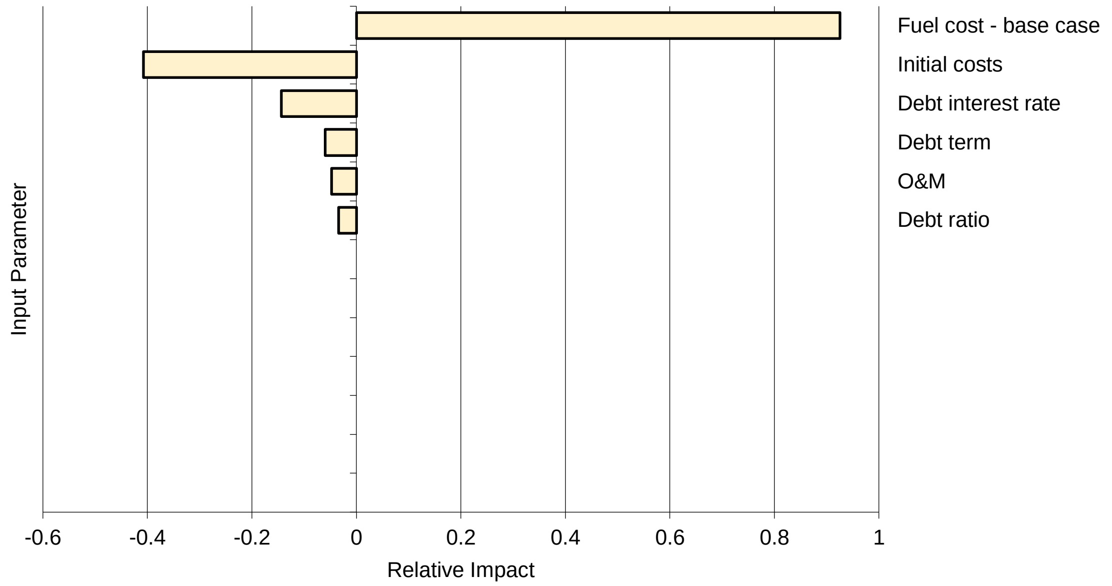


Figure A-49: Cumulative Cash-flow diagram for 5 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 50-50 biomass-diesel

Impact on NPV for 5 MW Gas Turbine Combined Cycle 50-50 Dual Fuel Biomass Model



Distribution of NPV for 5 MW Gas Turbine Combined Cycle 50-50 Dual Fuel Biomass Model

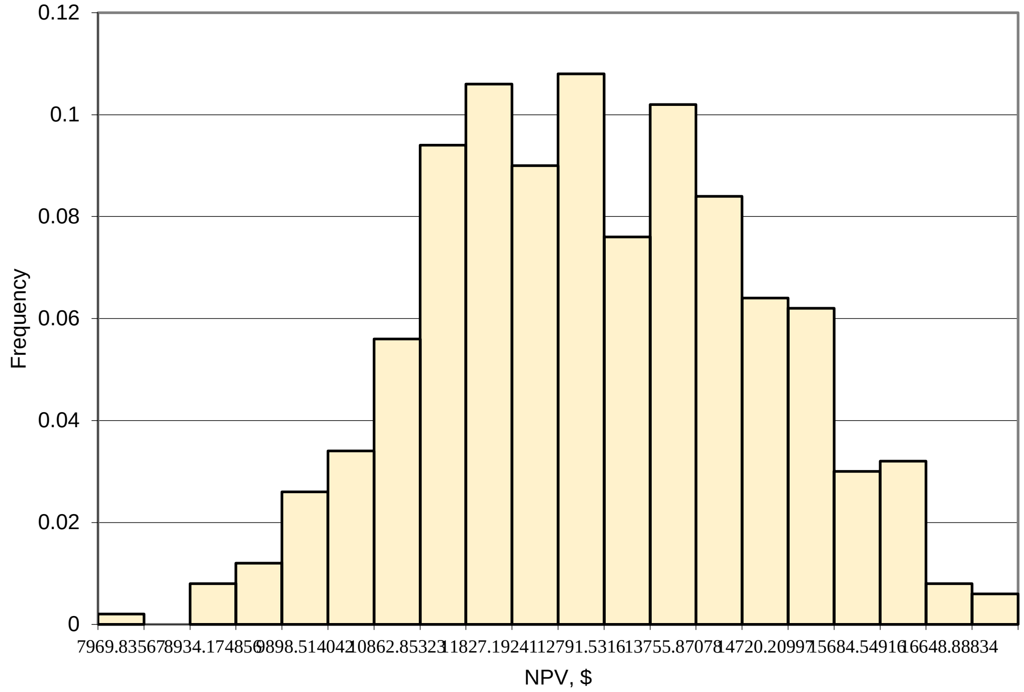


Figure A-50: Risk Analysis for 5 MW Gas turbine combined cycle biomass model having multifuel ratio 50-50 biomass-diesel

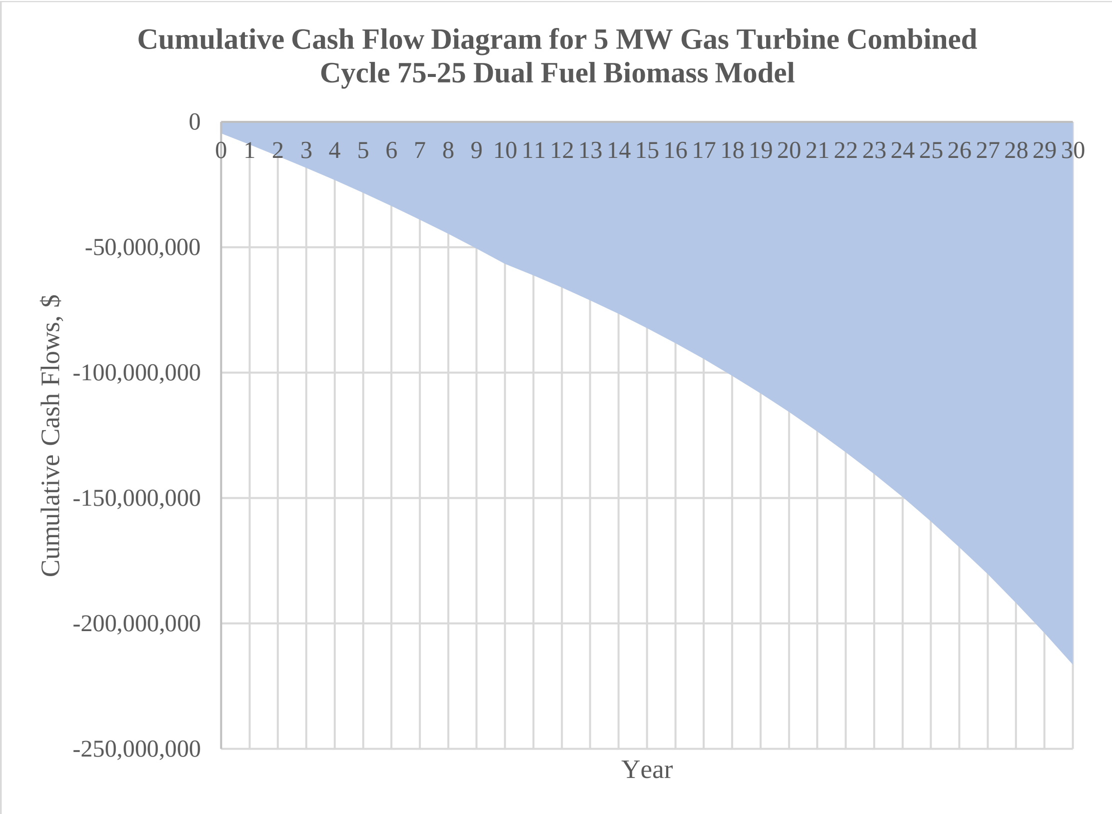


Figure A-51: Cumulative Cash-flow diagram for 5 MW Gas turbine Combined Cycle Biomass model having multifuel ratio 75-25 biomass-diesel

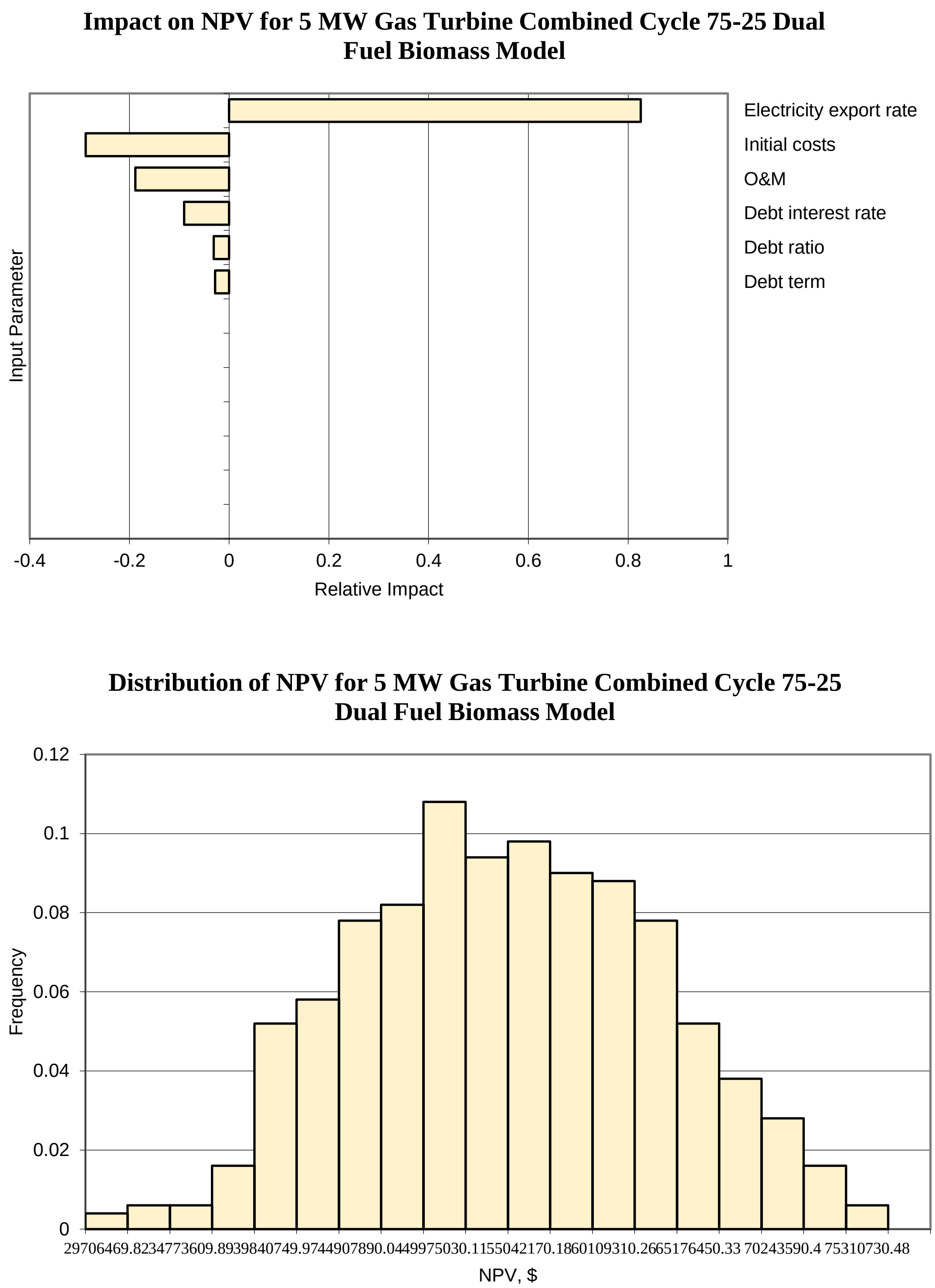


Figure A-52: Risk Analysis for 5 MW Gas turbine combined cycle biomass model having multifuel ratio 75-25 biomass-diesel

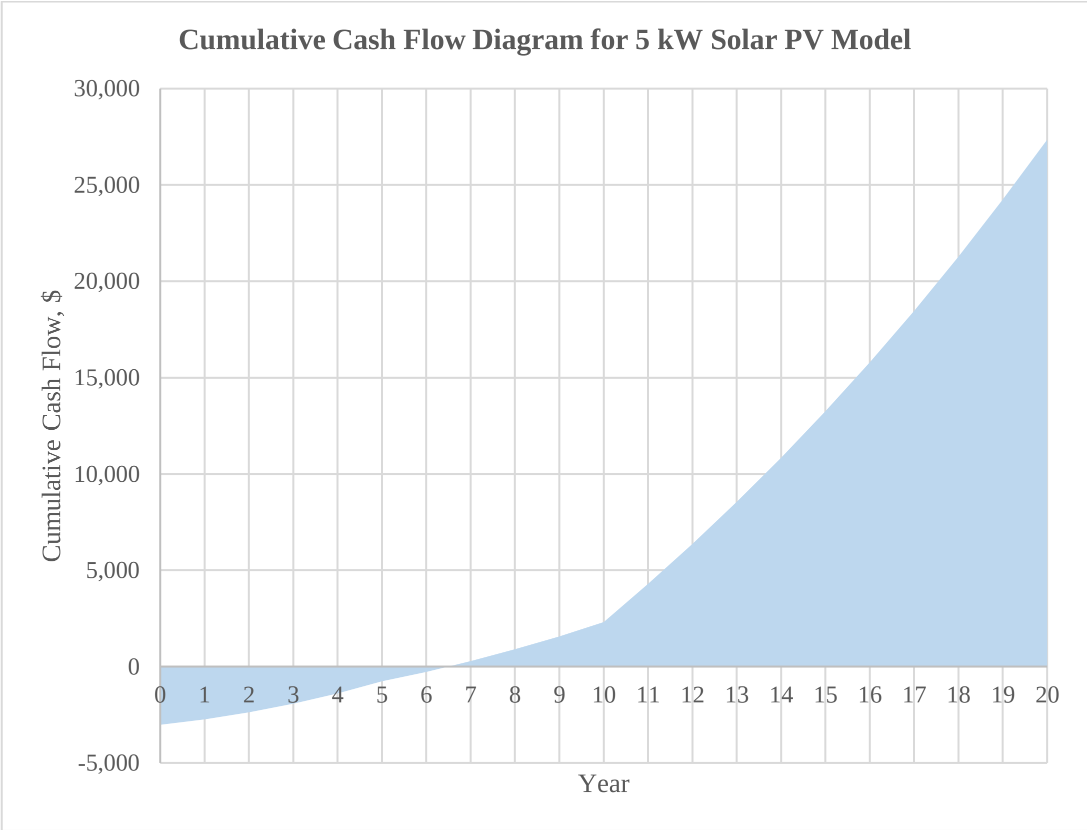


Figure A-53: Cumulative cash flow diagram for Solar PV model with capacity 5 kW

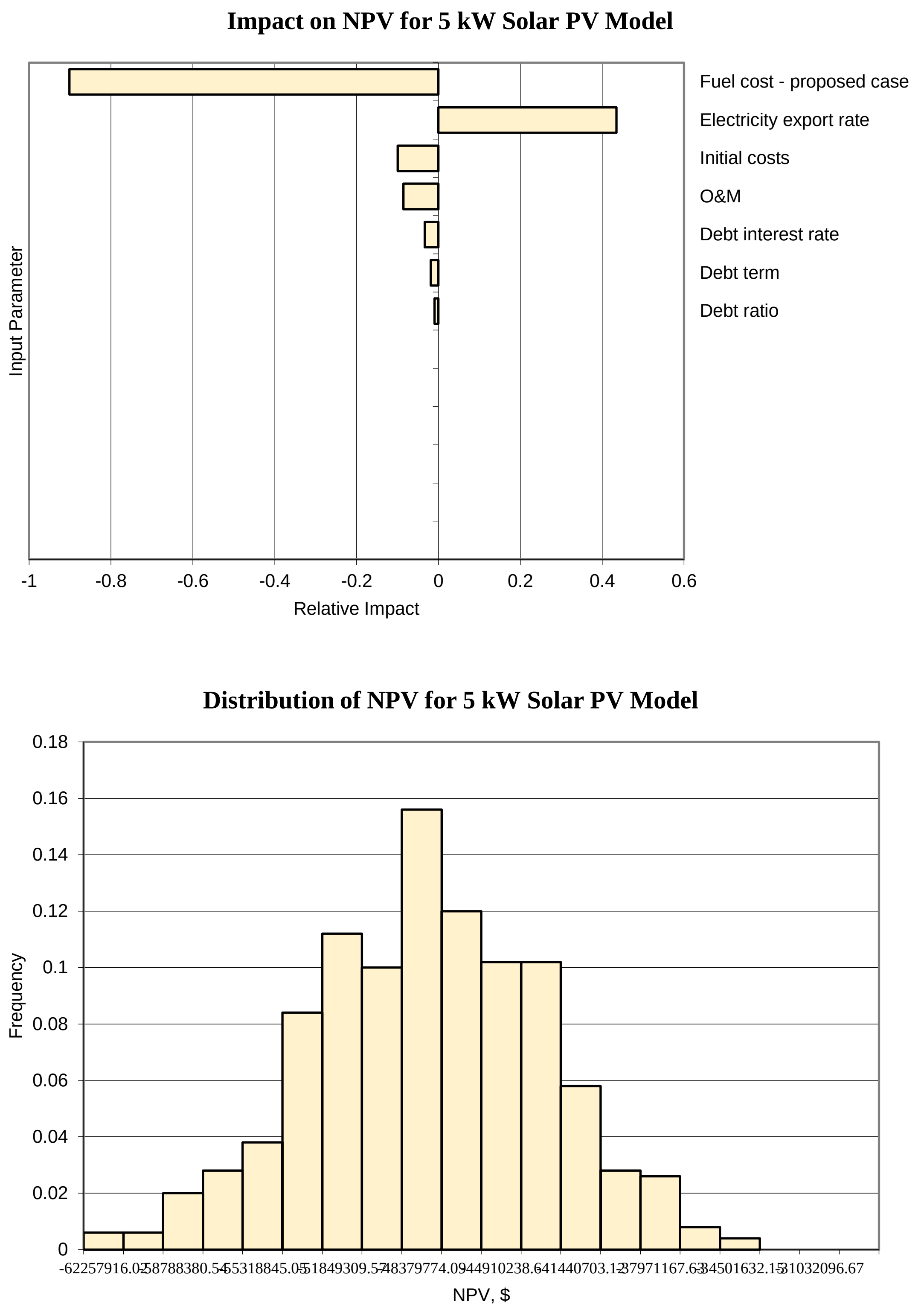


Figure A-54: Sensitivity analysis of 5 kW solar PV model

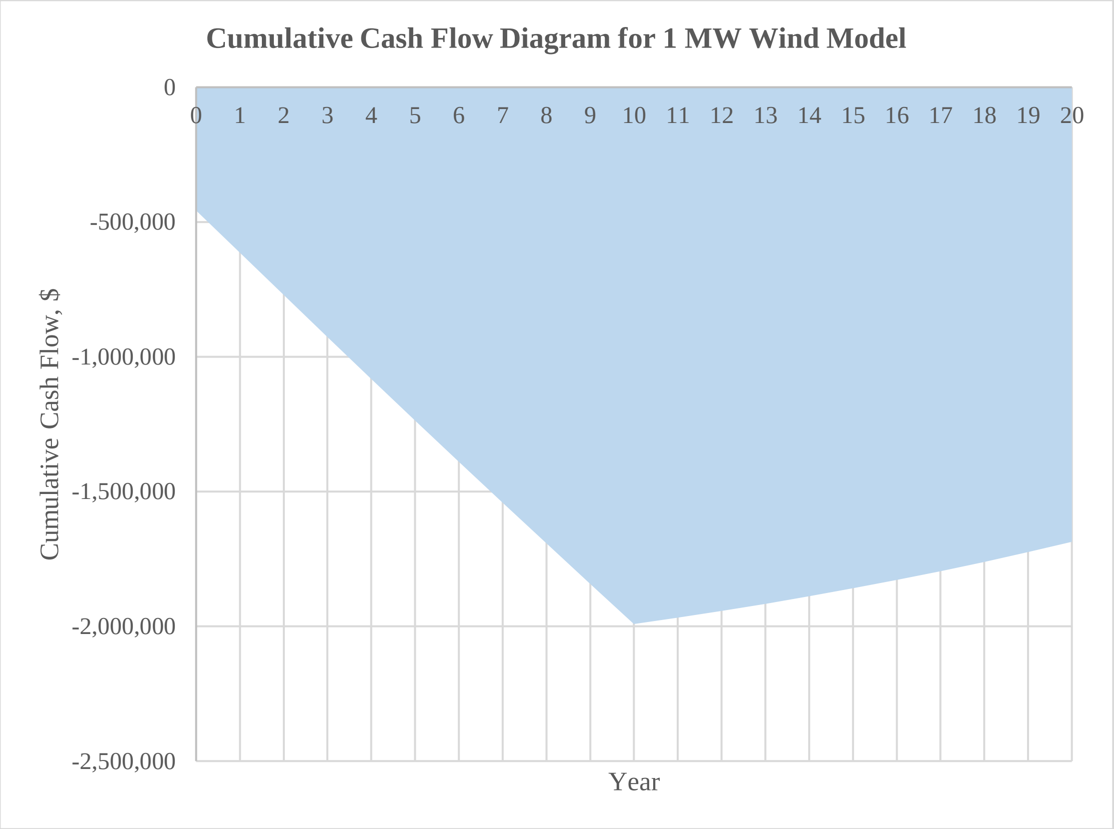
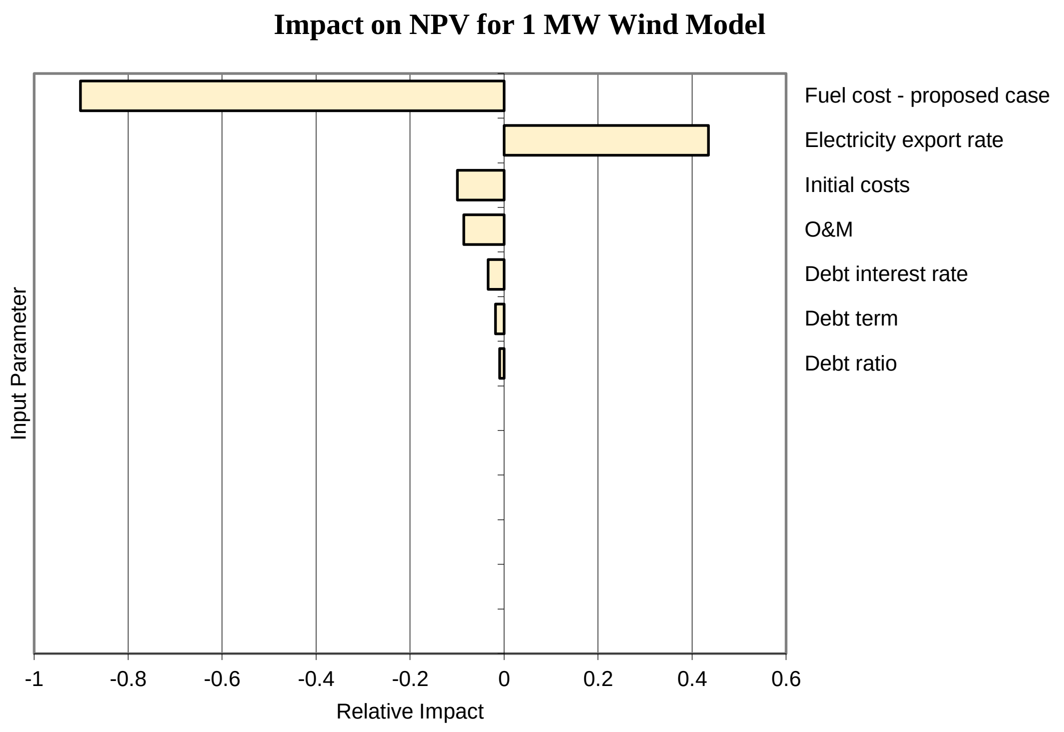


Figure A-55: Cumulative cash flow diagram of wind model with capacity 1 MW



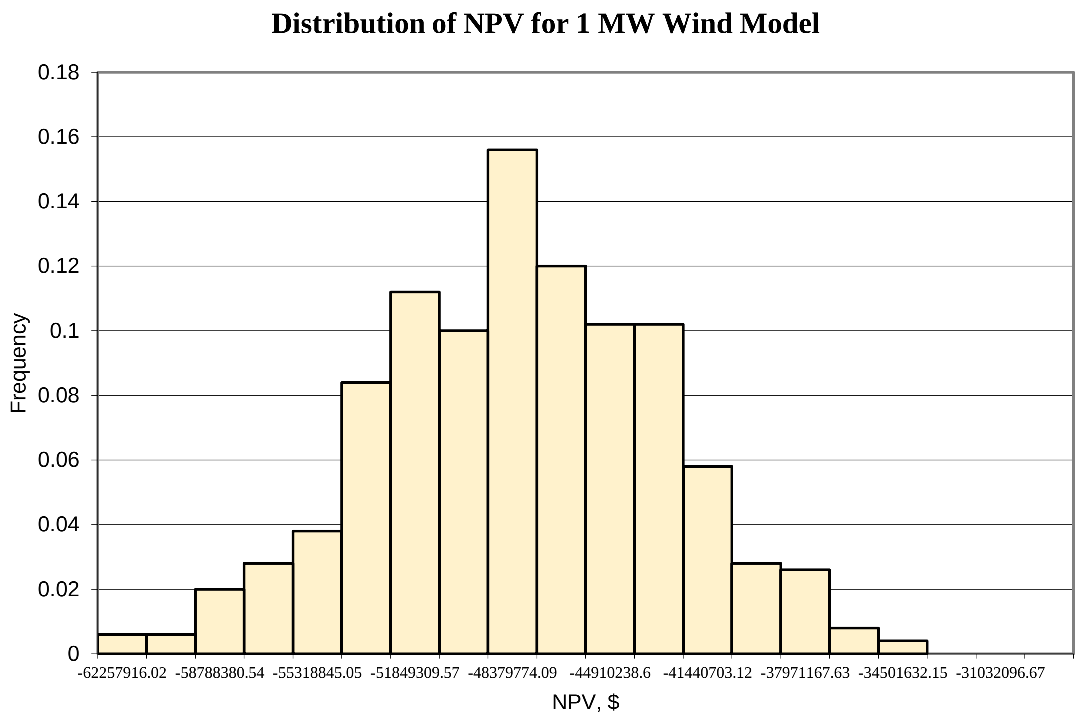


Figure A-56: Sensitivity analysis of wind model with capacity 1 *MW*

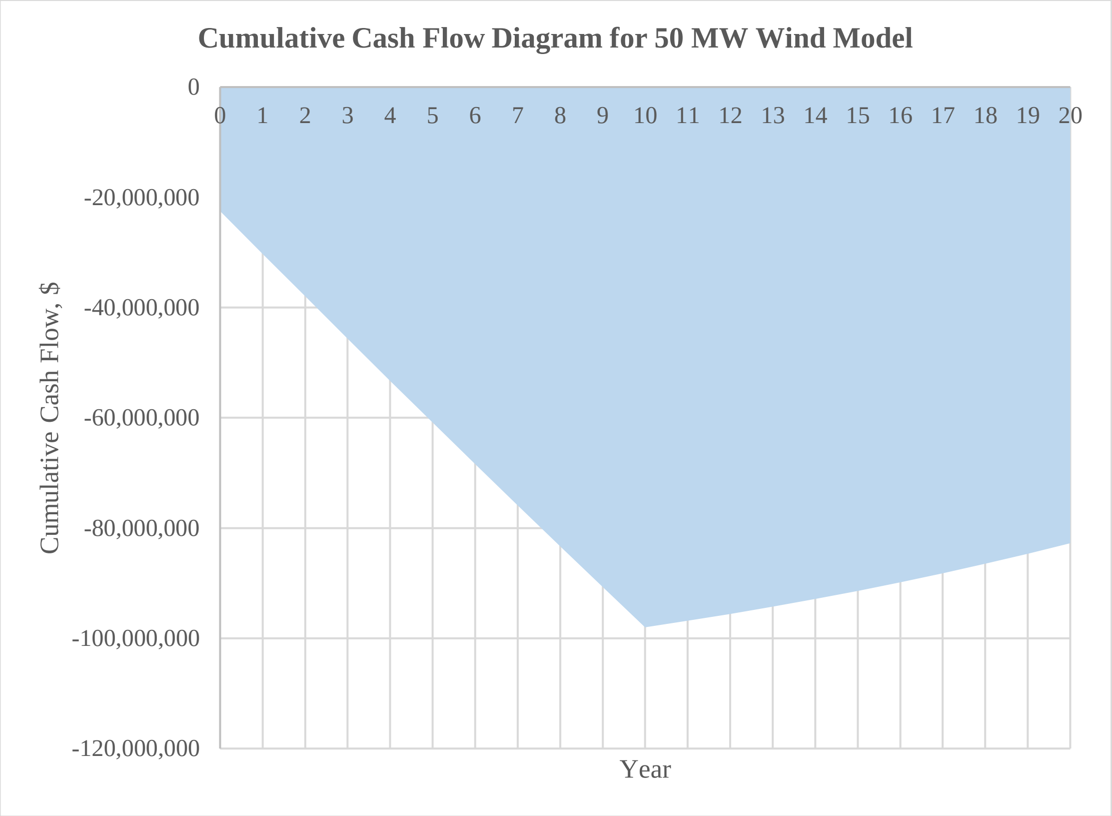
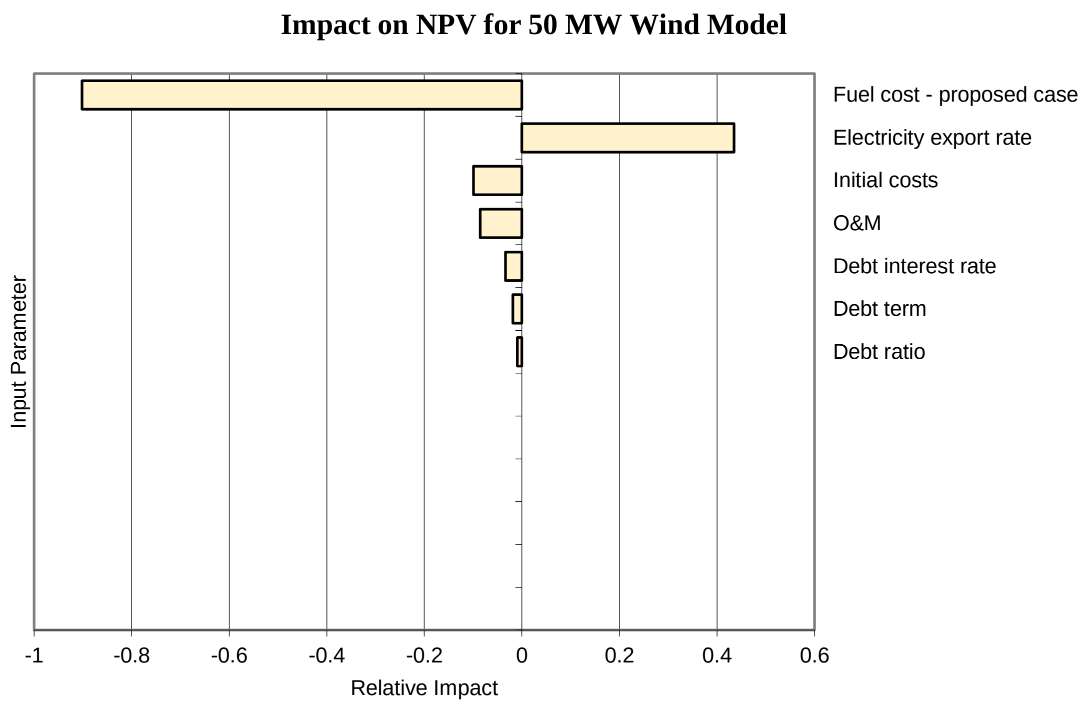


Figure A-57: Cumulative cash flow diagram of wind model with capacity 50 MW



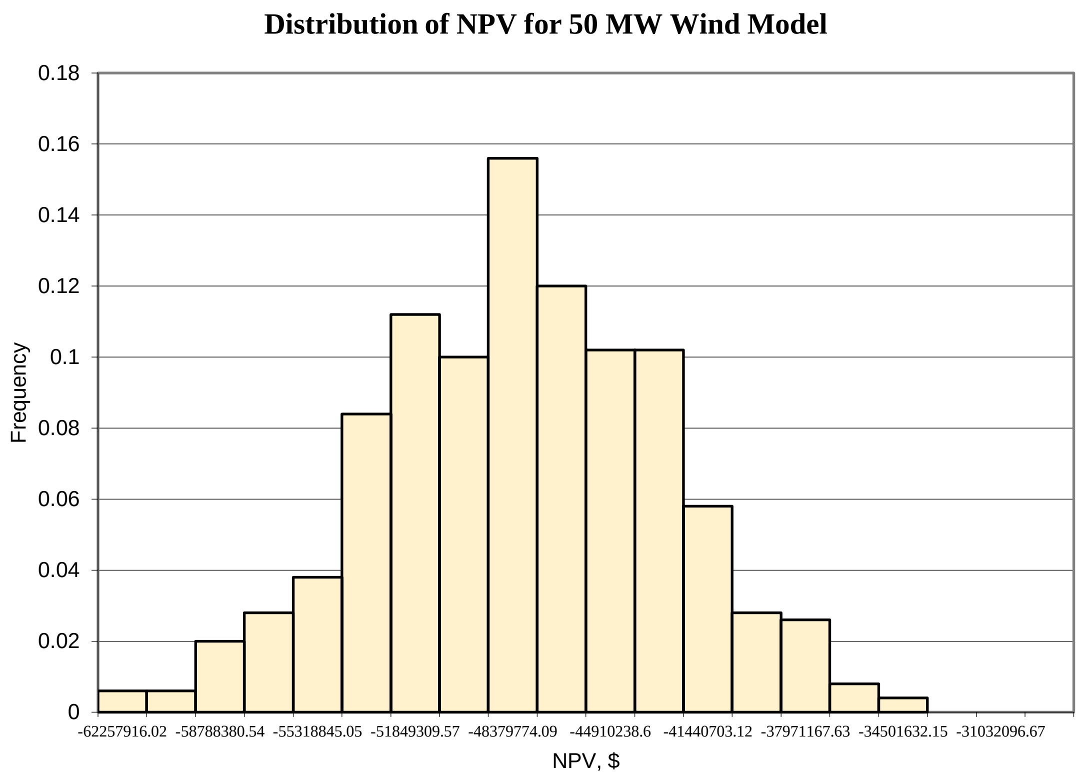


Figure A-58: Sensitivity analysis of wind model with capacity 50 MW

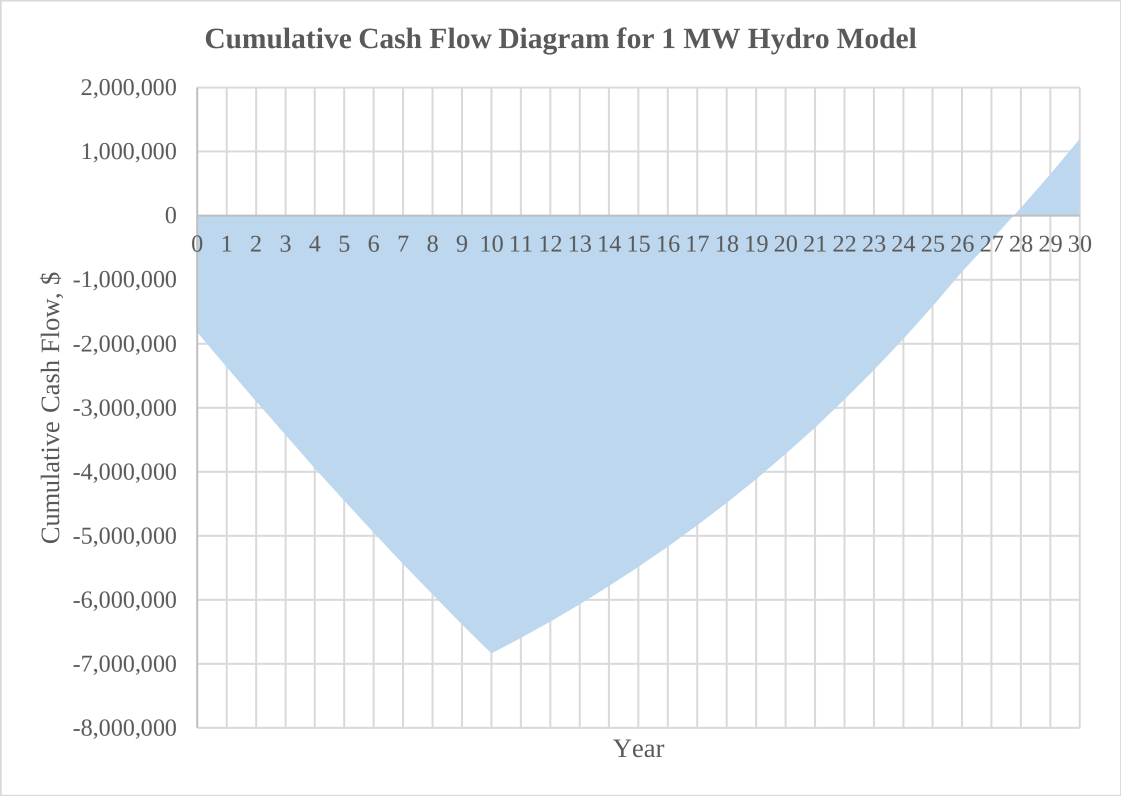
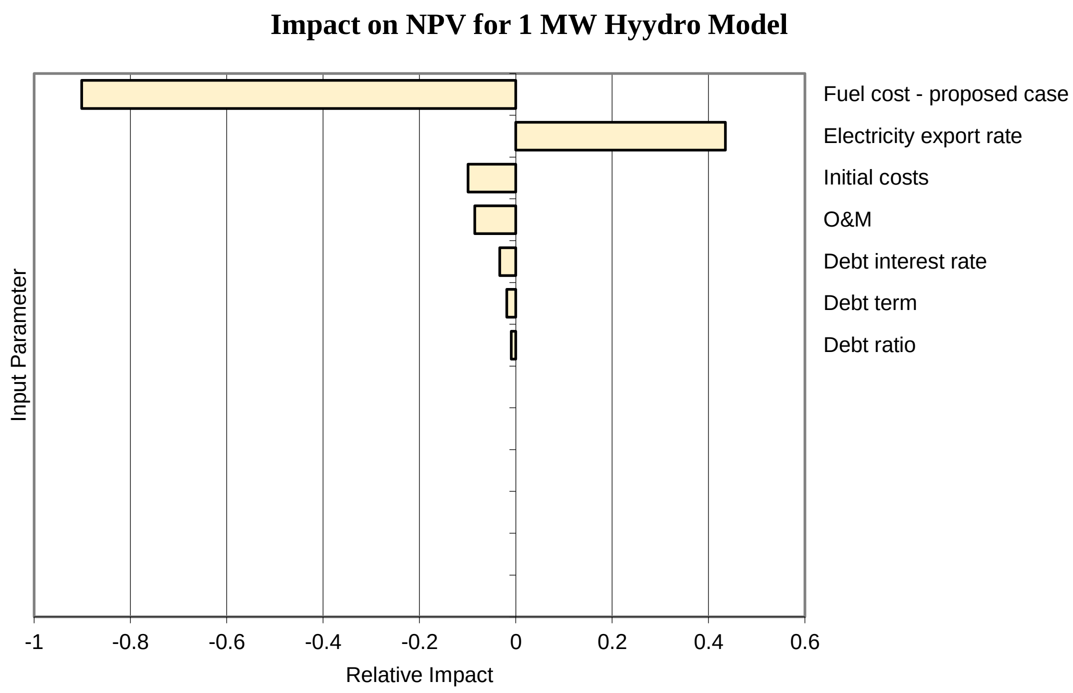


Figure A-59: Cumulative cash flow diagram of 1 MW hydropower project



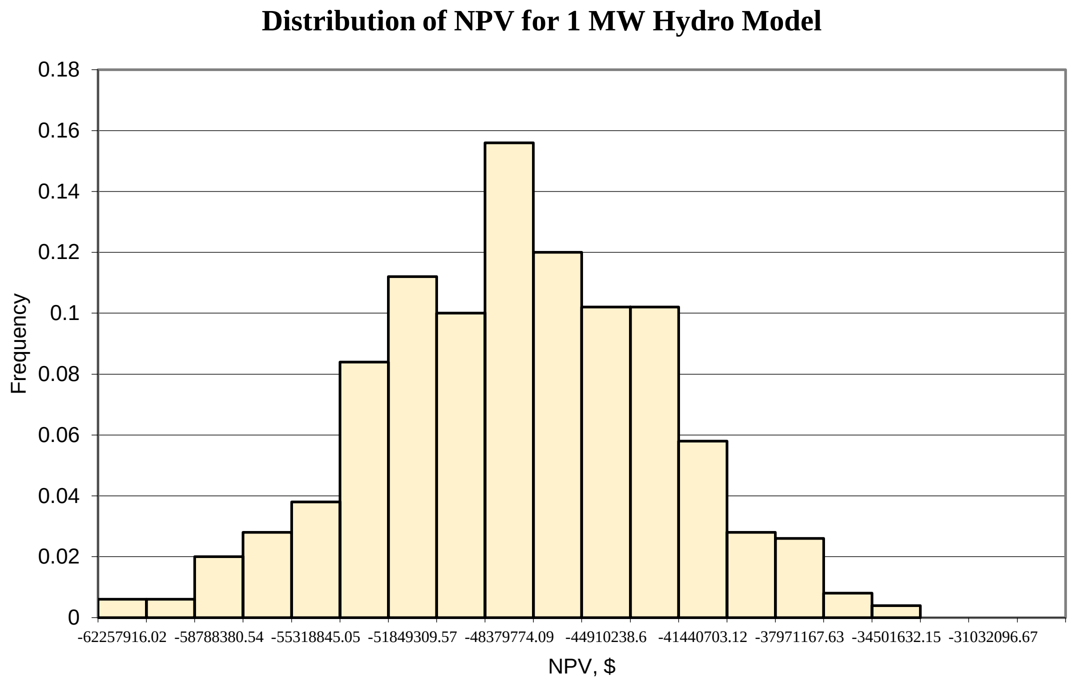


Figure A-60: Sensitivity analysis of the hydro model with capacity 1 MW