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The Cost-Benefit Feasibility Study of an On-Grid PV-Wind Hybrid Power System to Meet the Electricity Demand in the South-East Part of Bangladesh.

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Abstract

With a fossil fuel based power sector, mainly natural gas based, Bangladesh is suffering an acute shortage in both of electricity and natural gas. The most priority is given to the alternative sources of electricity to meet the increasing demand. Renewable energy sources are clean, environment-friendly and sustainable. The geographical position of Bangladesh is the best suitable for solar energy. Also the south-east part of the country is rich in wind energy. This paper represents a cost-benefit feasibility study of an on-grid PV-wind hybrid power system in Patenga, Chittagong, a region in the south-east part of Bangladesh. We use the electricity demand of hundred households for this study. HOMER optimization software is used to simulate the proposed hybrid system. The simulation shows that it will be feasible to use our proposed system as an alternative to diesel and high sulphur fuel oil (HSFO) based quick rental power plants presently used in Bangladesh.

Keywords: Renewable energy, On-grid system, Hybrid power, Fossil fuel, Quick rental power plant.

Introduction

In today's modern civilization, the availability of energy, more explicitly electricity, is the main indicator for all kinds of development and economic growth of a country. But Bangladesh has been suffering an acute power crisis for the last few years [1]. Only 53% people of the country have access to electricity and the per capita generation is only 265 kWh [2]. Moreover, the people being connected to the national grid are experiencing frequent load shedding [3]. At present the maximum generation is 6066 MW against the average demand of 7518 MW with a load shedding of 1452 MW [4]. Bangladesh depends mainly on fossil fuels for its electricity generation, especially on natural gas. Other sources based power plants are hydro electric power plant at Kaptai, the coal based power plant at Barapukiria and several small furnace oil and diesel power plants in the northern and southern region. In the FY 2011-12 the share of gas, hydro, coal, furnace oil and diesel based electricity generation was 79.15%, 2.21%, 2.52%, 11.86% and 4.27%, respectively [4,5].

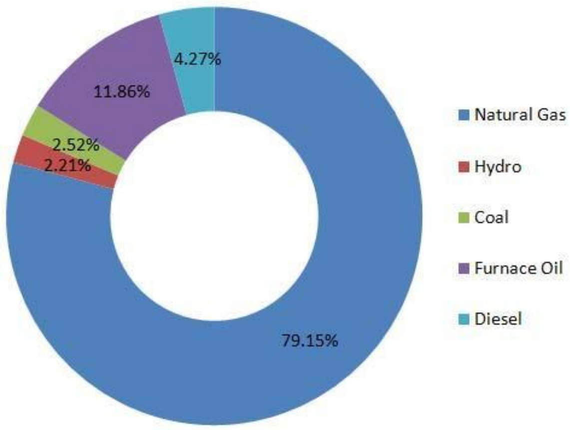


Figure 1: The share of different sources for electricity generation in Bangladesh.

The demand of electricity in Bangladesh is increasing rapidly due to the growth of almost each and every sector. Due to time limitations for coal mining, gas supply constraints and lack of other fossil resources, Government has entered into contractual agreements for high-cost temporary solution, such as rental power and small independent power producers (IPPs), on an emergency basis, much of it diesel or high sulphur fuel oil (HSFO) based. Under contracts between the Power Development Board (PDB) and the rental power producers (RPPs), the power development board (PDB) guarantees access to fuel by the RPPs at prices well below the rates charged by the Bangladesh petroleum corporation (BPC) to other consumers; for instance, diesel is sold to RPPs at $0.334(1 USD = 77.76 BDT) per liter compared to the regular BPC price of $ 0.874 per liter. On the other hand, the PDB power tariffs charged to consumers are lower than the prices the PDB spends to purchase power from generators. A BIDS (Bangladesh Institute of Development Studies) study estimated that the average cost of un-served energy is $0.344 per kilowatt-hour [6, 7].

Since the power stations are mainly dependent on natural gas, the country is facing a simultaneous shortage of natural gas and electricity [8]. The gas reserve of the country has fallen to such an alarming level that if no new reserves can be discovered then this reserve may last for another 6 to 7 years**.** The reserve for other fossil fuels is also decreasing and hence their price is increasing continuously. Again**,** the present nonrenewable energy sources have been causing negative effects (global warming, ozone layer depletion, acid rain etc.) on the atmosphere. So the only option to meet the power crisis for Bangladesh is to generate electricity from the alternative sources. Bangladesh has a vast potential for renewable energy. Geographically the location of Bangladesh is an ideal one for solar energy utilization. The coastal areas, offshore islands and northern part of the country have a potential of wind energy [1, 9]. We can use these renewable energy sources to meet the increasing electricity demand and to minimize the negative effects on environment.

This paper presents a cost-benefit feasibility study of an on grid PV-wind hybrid power system in Patenga, Chittagong, a region in the south-east part of Bangladesh. The study is performed using HOMER (Hybrid Optimization Model for Electric Renewable) optimization tool developed by National Renewable Energy Laboratory (NREL).

Resources for hybrid system

A hybrid renewable energy system consists of renewable energy source working together with a non-renewable energy source. In this study, the renewable energy sources are solar energy, wind energy and the non-renewable energy source is the utility grid. The renewable energy sources will generate electricity to be used by the load and the grid is used as back-up. The resources which are utilized for electricity generation for hybrid power system are discussed below.

Solar resource

Solar energy is the most common form of renewable energy and it is inexhaustible and pollution free. This energy comes to our earth in the form of electromagnetic radiation and is available everywhere on the earth surface. But the amount depends on the distance from the sun and hence the greatest amount is available between two broad bands encircling the earth between 15˚ and 35˚ latitude north and south. Fortunately, Bangladesh is situated between 20˚43′ and 26˚38′ north latitude which is a very favorable position for the utilization of solar energy [10, 11]. The daily solar radiation in Bangladesh varies between 3.8 and 6.5 kWh/m^2 [12]. The latitude and longitude of the area selected for this study are 22˚22′ north and 91˚50′ east, respectively. The daily solar resource profile for the selected region is shown in figure 2. This solar data is obtained by HOMER for the coordinates. The annual average solar radiation is 4.76 $kWh/m^2/d$, which is best suitable to generate electric energy with PV.

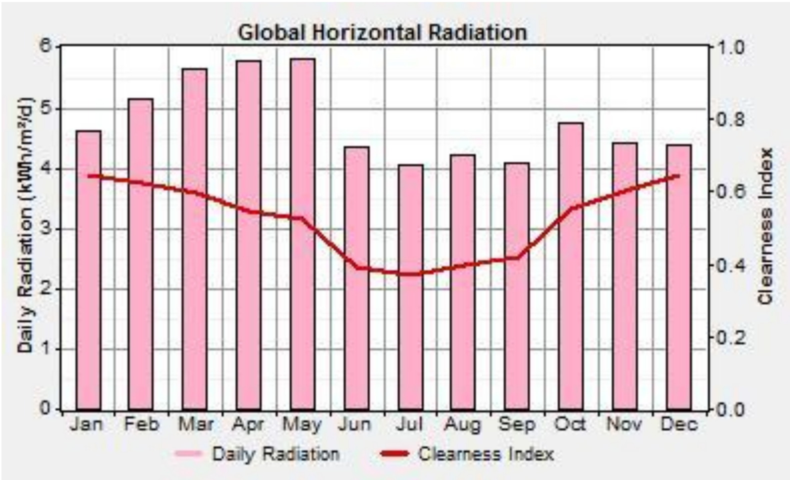


Figure 2: Monthly averaged solar radiation and clearness index data.

The clearness index is a measure to classify the atmosphere as clear or cloudy. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth and defined as the surface radiation divided by the extraterrestrial radiation. It is a dimensionless number whose value ranges between 0 and 1. A high value of clearness index indicates a clear, sunny day, and a low value indicates cloudy conditions [13, 14].

Wind resource

Wind energy is now the world's fastest growing renewable source and almost every country of the world uses this energy source to generate electricity as it is pollution free and sustainable. But in Bangladesh, research in this field began only a few years ago, which had shown that some southern districts of the country have a very good potential of wind energy [15, 16]. The potential is mainly limited into the coastal area where the wind velocity is considerably higher. The locations are widely dispersed along the vast coastline in the district of Cox’s Bazar, Chittagong, Noakhali, Bhola and Patuakhali [11]. In Bangladesh, wind is available mainly during the Monsoons and around one to two months before and after the Monsoon. Wind either remains calm or is too low during the months starting from late October to the middle of February. If a windmill is properly designed and located a noticeable supply of wind energy can be found, except for the above mentioned four months, to use in the purpose of electricity generation [17]. The selected area for this study is Patenga, Chittagong. The wind speed data for duration of twelve months in the proposed area is shown in figure 3**.**

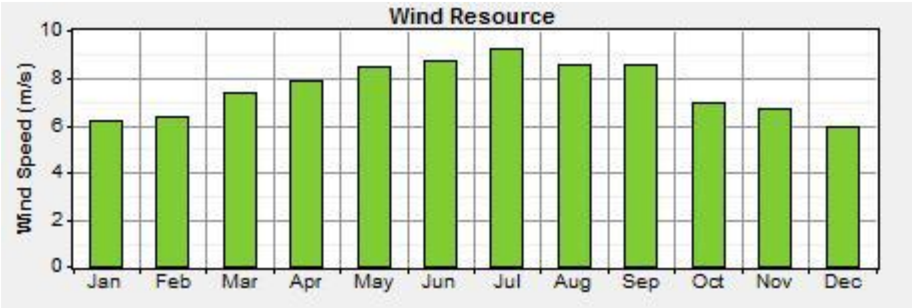


Figure 3: Monthly averaged wind speed data [18].

For the selected area the average wind speed ranges from 5.91 m/s to 9.2 m/s with an annual average of 7.576 m/s. The Weibull parameter (k) describes the breadth of distribution of wind speeds over the whole year and the value assumed for this parameter is 1.85 with an autocorrelation factor of 0.7. Lower k values correspond to broader distributions of wind speed and higher values correspond to narrower wind speed distributions. The diurnal pattern strength that reflects how strongly the wind speed tends to depend on the time of day is 0.32.

Utility grid

The electric power grid is like a battery with much better efficiency rates but does not require maintenance or replacements [19]. When the renewable energy supply is insufficient, electricity will be bought from the grid. When the renewable energy generates excess electricity, it will be sold back to the grid using Feed in Tariff (FiT) rates. About 97.79% [4] of the grid power in Bangladesh is based on fossil fuels, which are not environment friendly and are responsible for the global warming**.** The one and only renewable energy based hydro power plant with a generation capacity of 230 MW is located in Kaptai (Rangamati district) across the river Karnafuli [20].

Load profile

For this paper, energy consumption data for several grid-connected houses in Patenga, Chittagong is collected and then averaged to get the monthly energy consumption for 100 of such households. We collected the energy consumption data from the monthly electric bill for a year (From July, 2012 to June, 2013). The amount of energy consumed by a typical residential house in the proposed area is given in table 1.

Table 1: Monthly energy consumption in a typical residential home.

Month	Energy consumption (kWh/month)
July	340
August	330
September	315
October	350

November	330
December	305
January	290
February	330
March	360
April	450
May	400
June	370

Figure 4 shows the hourly load profile for a day in the month of April for the proposed area. The average daily load profile for the whole year is shown in figure 5. In a day, power consumption is higher in the evening and as a month energy consumption is higher in April. On an average the daily load demand is 1132 kWh/day and the peak demand is 118 kW.

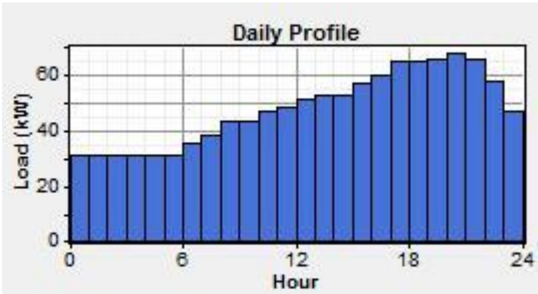


Figure 4: Hourly load profile for a day in the month of April for the proposed area.

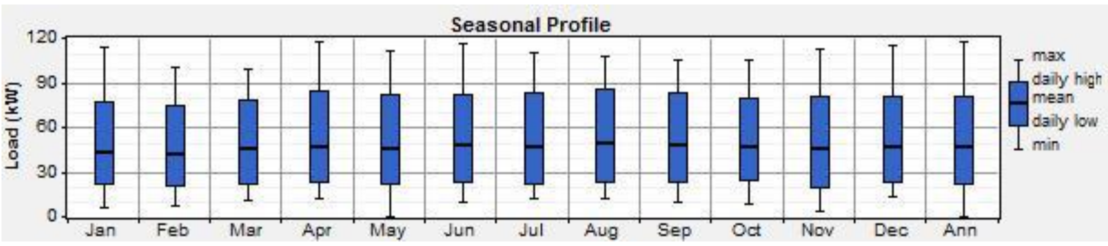


Figure 5: Averaged monthly load data for the proposed area.

Hybrid system components

The proposed on grid PV-wind hybrid system consists of PV panel, wind turbines, converters (inverters) and grid. For economic analysis, HOMER includes the initial cost, replacement cost, and operating and maintenance cost. The cost for this study is estimated considering the market price of Bangladesh.

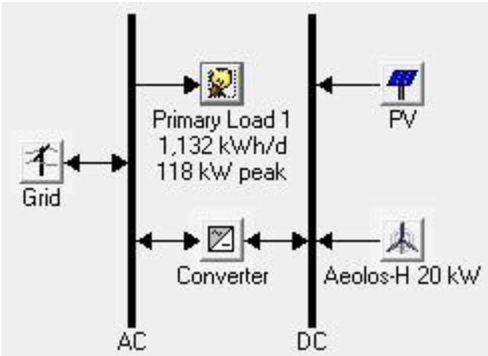


Figure 6: HOMER Configuration of the proposed on grid PV-wind hybrid system.

PV panel

A PV panel converts the light energy incident on it to electrical energy. The PV panels chosen for the system are the crystalline solar panels as they have higher efficiency, about 21.5% [21], and longer lifetime. Table 2 shows the cost and other related parameters of solar PV panel which are considered for designing the hybrid system.

Table 2: Cost and other parameters of solar PV panel.

Parameter	**Unit**	**Value**
Capacity	kW	1
Capital cost	$	3000
Replacement cost	$	2500
Operation and maintenance cost	$/yr	2
Lifetime	Years	25
Derating factor	Percent	85.5

Wind turbine

The amount of energy available from the wind turbine greatly depends on wind variations. Therefore, wind turbine rating is generally much higher compared to the average electrical load [22]. In this paper, Aeolos-H 20kW Wind turbine is considered [23]. Table 3 represents the cost and operational parameters of the wind turbine.

Table 3: Cost and operational parameters of Aeolos-H 20kW wind turbine.

Parameter	**Unit**	**Value**
Rated power	kW	20
Starting wind speed	m/s	3
Rated wind speed	m/s	16
Cut-off wind speed	m/s	25

Capital cost	$	55160
Replacement cost	$	41370
Operation and maintenance cost	$/yr	1200
Lifetime	Years	25

Converter (Inverter)

An inverter converts direct current (DC) to alternating current (AC) which is used by the majority of electrical appliances. In addition to this some inverters, known as grid-tie inverters or grid-interactive inverters, synchronize the phase and frequency of the current to fit the utility grid. Grid-tie inverters also adjust the output voltage slightly higher than the grid voltage so that the excess electricity generated by the system can flow outwards to the grid [19].In this study a grid connected true sine wave power inverter is considered as it produces the closest to a pure sine wave of all power inverters and in many cases produces cleaner power than the utility company itself [24]. Table 4 represents the technical and economic parameters of the inverter considered for the proposed system.

Table 4: The technical and economic parameters of the inverter.

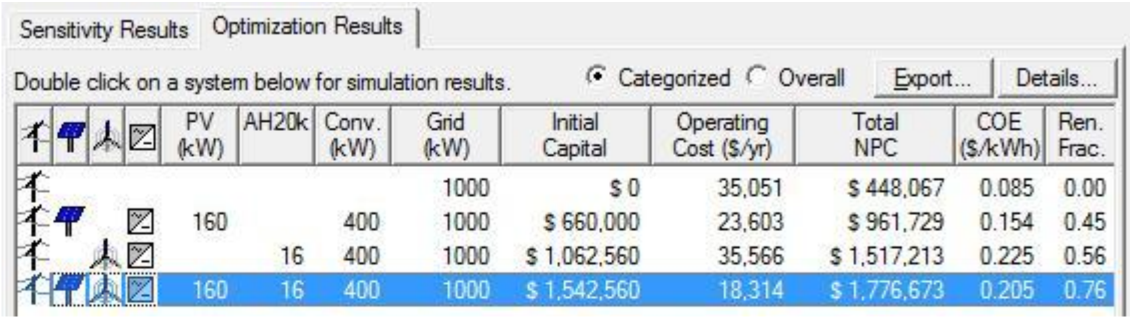
Parameter	**Unit**	**Value**
Capacity	kW	10
Capital cost	$	4500
Replacement cost	$	3600
Operation and maintenance cost	$/yr	50
Lifetime	Years	15
Efficiency	Percent	90

Grid input

In Bangladesh the average selling price of grid power is lower than the average generation cost, selling price is about 60% of the average generation cost [25].For residential customers, the grid power price, the price of electricity bought from the grid, differs according to kilowatt-hours (kWh) used in a month. But HOMER has a limitation in inputting several prices based on kWh used in a month and multiple price rates are only applicable if the rates differ according to the time of day or the day of the year [26]. Hence, in this study we consider the average price for a house whose monthly power consumption ranges between 301 kWh and 600 kWh and the price for this range is $0.083/kWh. We also apply the same price as feed-in-tariff, the price of electricity sold to the grid, only to give price value for the excess power generated by the renewable energy sources. The demand rate is $0.579/kWh/month [27].

Results and discussion

HOMER simulates a system configuration by comparing the electric load in a time step to the energy available in the system in that time step supplied by each of the components. After simulation HOMER shows a list of all the possible system configurations sorted by net present cost (NPC). Besides showing feasible system configurations, HOMER also evaluate the operational characteristics such as component wise and total electricity production in a year, annual electricity consumption, annual electricity sold to the grid, excess electricity, unmet electric load, capacity shortage and renewable energy fraction, for each of the feasible system configuration. Figure 7 shows the economically feasible configurations and table 5 shows the electrical simulation result for our proposed system.


Sensitivity Results | Optimization Results

Double click on a system below for simulation results. (•) Categorized ( ) Overall [Export...] [Details...]

	PV (kW)	AH20k	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
				1000	$ 0	35,051	$ 448,067	0.085	0.00
	160		400	1000	$ 660,000	23,603	$ 961,729	0.154	0.45
		16	400	1000	$ 1,062,560	35,566	$ 1,517,213	0.225	0.56
	160	16	400	1000	$ 1,542,560	18,314	$ 1,776,673	0.205	0.76

Figure 7: Optimized simulation results from HOMER**.**

The PV system provides 33 percent of the load, 45 percent is supplied by the wind turbines and the other 22 percent comes from the grid (table 5).The 61 percent of the energy produced by the proposed system is used to serve the load demand and the remaining 39 percent energy is sold to the grid during the year and that happens when the PV panels and wind turbine produce more power than the demand. Excess electricity fraction is almost zero percent. There is no unmet electric load and capacity shortage is zero. The renewable fraction is 0.757 and the maximum renewable penetration is 128%.

Table 5: Electrical simulation results.

	Energy Production	
Production	**kWh/yr**	**%**
PV array	241,919	33
Wind turbines	327,539	45
Grid purchases	164,545	22
Total	734,003	100
	Energy Consumption	
Consumption	**kWh/yr**	**%**
AC primary load	413,180	61
Grid sales	263,644	39
Total	676,824	100

	Energy Quantity	
Quantity	**kWh/yr**	**%**
Excess electricity	261	0.04
Unmet electric load	0	0
Capacity shortage	0	0
	Renewable Fraction	
Quantity		**Value**
Renewable fraction		0.757
Max. renew. penetration		128%

The monthly electric energy produced by each of the components is given in figure 8. From the figure we find that the PV production is high in the months of January to May because of higher clearness index and low in the months of June to September for lower clearness index. The wind turbine production is high in the months of April to September because of higher wind speed in these months.

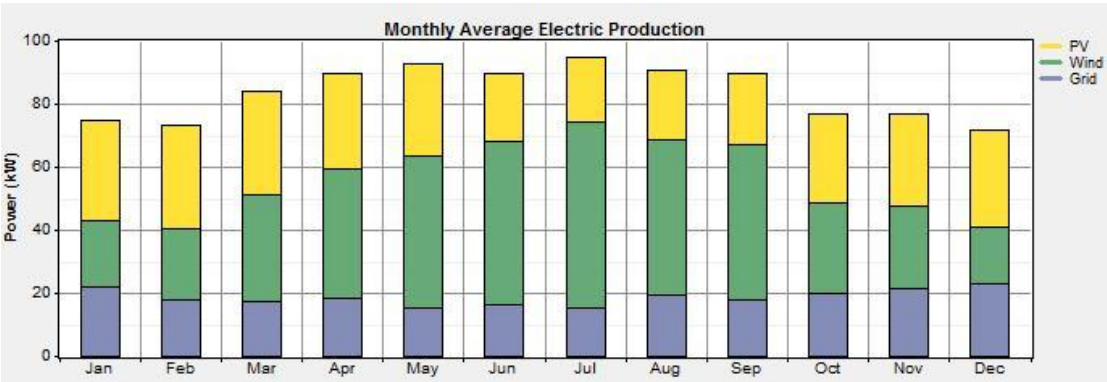


Figure 8: Monthly average electric energy production.

Table 6: Monthly energy bought from and sold to grid.

	Energy	Energy	Net	Peak	Energy	Demand
	Purchased	**Sold**	**Purchases**	**Demand**	**Charge**	**Charge**
Month	**(kWh)**	**(kWh)**	**(kWh)**	**(kW)**	**($)**	**($)**
Jan	16,513	18,530	-2,017	113	-167	65
Feb	12,217	16,393	-4,176	94	-347	54
Mar	12,989	22,871	-9,882	90	-820	52
Apr	13,447	24,825	-11,378	112	-944	64
May	11,414	28,485	-17,072	102	-1,417	59
Jun	11,882	24,317	-12,435	97	-1,032	56
Jul	11,284	29,384	-18,100	107	-1,502	61
Aug	14,412	24,567	-10,156	105	-843	61
Sep	12,836	24,340	-11,504	101	-955	58

Oct	14,992	17,687	-2,695	99	-224	57
Nov	15,495	17,835	-2,340	108	-194	62
Dec	17,066	14,411	2,655	111	220	64
Annual	164,545	263,644	-99,099	113	-8,225	714

The cost summary for the optimum solution of the proposed model is given in table 7 and table 8. The wind turbine has the highest capital cost. PV and wind turbine have no replacement cost as their lifetimes are same as the project lifetime considered. All cost associated with grid is considered as operating cost and in this case it is negative, since the total energy sold yearly to the grid is higher than the energy bought from the grid. The total net present cost (NPC) is $1,776,673, the operating cost is $18,314/yr and the cost of energy (COE) is $0.205/kWh.

Table 7: Component wise cost.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	480,000	0	10,227	0	0	490,227
Aeolos-H 20 kW	882,560	0	245,441	0	0	1,128,001
Grid	0	0	-96,023	0	0	-96,023
Converter	180,000	60,086	25,567	0	-11,184	254,469

Table 8: System cost.

Parameter	Unit	Value
Total net present cost (NPC)	$	1,776,673
Operating cost	$/yr	18,314
The cost of energy (COE)	$/kWh	0.205

Conclusion

The increasing energy demand, depletion of the fossil fuel reserves and the pollution caused by conventional energy sources have made it necessitous to search for alternative energy sources. Renewable energy sources are the only option to meet all the requirements. In this paper, we simulate an on grid PV-wind hybrid system using HOMER software. The cost of energy for the proposed system is $ 0.205/kWh and the system is environment friendly, because the system will emit less green house gases as compare to conventional power plants. On the other hand, the average cost of un-served energy from quick rental power plant is $0.344/kWh. So it will be feasible to use our proposed system as an alterative to diesel and high sulphur fuel oil (HSFO) based quick rental power plants and reduce the negative impact on the atmosphere.

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