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Sustainable agrivoltaic system for food and energy sector in Bangladesh

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ABSTRACT

In South Asia, agriculture heavily relies on groundwater for irrigation. The withdrawal is nearly 250 km^3 annually. Approximately, 12 million electric and 10 million diesel water extraction pumps, totaling about 22 million, are in use in this area. In contrast, while PV-powered solar irrigation pumps are becoming more popular, they take up agricultural land, increasing the competition for land resources between food and clean energy production. It is left unattended during the off-season, wasting a lot of potential solar power that could produce green electricity. To address this, an integrated farming model can be established, utilizing existing solar pump facilities for crop cultivation, rearing Black Bengal Goats, and native fish farming. This diversified approach combines sustainable energy solutions with solar irrigation, generating both agricultural products and electricity while maintaining agricultural land for cultivation and promotion of clean energy production. The proposed method has produced both agricultural products and electricity simultaneously. This integrated system offers a solution to the challenges faced in the region, balancing food production and clean energy goals effectively.

Keywords: Agrivoltaic; Solar irrigation pump; Goat farming; Fish farming

Introduction

Bangladesh is considered one of the fastest growing economies in the Southern-Asia, with 64% of the total population living in rural areas (World Bank, 2021). Bangladesh is ranked as 8^{th} in the world's largest populated countries (Worldometer, 2023) The country has a very limited energy reserve, small amounts of oil, coal, and countable natural gas reserves. The country suffers an internal energy struggle, as about 56.43% of the country's powers producing thermal plants are gas-based, but the gas is also needed for the industrial sector (Bangladesh Economic Review, 2022). Therefore, the country must continuously make some compromises between power production and developing the industrial sector. The power sector in Bangladesh is highly dependent on fossil fuels, as natural gas and coal are the dominating sources for power generation in the country. About 44.53% of Bangladeshi generated electricity comes from natural gas, while 10% is from diesel, 6.86% comes from coal, 24.36% of heavy oil, imported 4.5% and 3.68% is of renewable sources (BPDB, 2022). Even though the Bangladeshi energy sector uses and covers varied products; electricity, petroleum products, natural gas, coal, biomass and solar, yet the policy and decision makers are mostly pre-occupied with electricity, as it is the most common used form of energy in the country. Thus, because there is a continuous and rapidly widening gap between electricity supply and demand, therefore it is a major challenge for the energy sector in Bangladesh. A situation which deteriorates during irrigation seasons when the demand-supply gap reaches up to 1500 MW (Bangladesh Economic Review, 2022).

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The country possesses great potential for solar energy, with average solar energy incident about 4-6.5 kWh/m2/day, and averaging 10.5 hours of sun per day, of which 4-4.5 are peak sunlight hours and 300 clear sunny days per year (SREDA, 2021). Currently, the country is considered a market leader when it comes to SHS, and standalone PV systems (SREDA, 2021). Solar based irrigation systems are innovative and environment friendly solution for the agro-based economy of Bangladesh. The deployment of Photovoltaic (PV) power generation and modern techniques in agriculture has the potential to simultaneously address the Sustainable Development Goals (SDG) of which is SDG-1 (No Poverty), SDG-2 (zero hunger), SDG-3 (Good Health and Wellbeing), SDG-5 (Gender Equality, SDG-7 (affordable and clean energy), SDG-8 (Decent work and Economic Growth), SDG-9 (Industry, Innovation and Infrastructure), SDG-11 (Sustainable Cities and Communities), SDG-12 (Responsible Consumption and Production) and SDG-13 (Climate Action).

The world's population has tripled in the past ten years, which has resulted in a massive rise in both energy and food production. A sizeable amount of the land must be set aside to produce food and energy to feed and power this growing population (Food and Agriculture Organization, 2017). On the other hand, it's going to be harder than it has been so far to meet the need for additional energy and food in the coming decades. Global climate change is another issue that is causing many natural processes involved in the production of modern energy and food to be disrupted. The overexploitation of species via farming, biodiversity loss due to habitat degradation, pollution, and heavy use of land and water resources are some of the main factors contributing to the global climate change. Lands experience soil erosion and chemical pollution from chemical fertilizer because of substantial agricultural activity. To address these needs in a sustainable way, development of effective and integrated production systems is essential. Integration of solar power production facilities on agricultural areas can be mutually advantageous in the production of energy and food as a solution to those issues (Barron-Gafford *et al.* 2019; Dupraz *et al.* 2011). Thus, much recent research has concentrated on methods to increase solar energy's compatibility with the environment. The integrating solar power generation with other land uses has amplified the shared advantages of maintaining ecological balance by retaining soil and water, sequestering carbon, and possibly enhancing nearby agriculture (Walston *et al.* 2021; Weselek *et al.* 2019).

This paper proposes Integrated Farming and surplus energy sharing from the existing solar irrigation pump (SIP) resources like land, water, and energy. The approach will lead an integrated farming model alongside climate-friendly green energy solutions for long-term solar irrigation that combines financial stability, and income mobilization and contribute to the country's power system by sharing surplus renewable and green energy in the national grid. The proposed Integrated Farming system rearing of the Black Bengal Goat (BBG) alongside native fish farming in the SIP site and a green energy model illustrates the optimum use of its fallow land and export energy to the grid. Besides energy the place where solar panel was installed it can be converted into a production hub of agriculture, livestock, fisheries and an interactive place of the community with the available facilities of income generation activities (Andrew *et al.* 2021). The outcome of the research work is to help agriculture to diversify its revenue and agricultural practices through solar energy generation while keeping land for agricultural use.

Materials and methods

To validate the proof of concept a pilot study was conducted in a Solar Irrigation Pump (SIP) site in Chuadanga and Jhenaidah districts of Bangladesh. Which lies between latitude and longitude 23.7031850, 88.7833400 and 23.328471, 88.779980 respectively. The climate of the site locations is drought and humid. Overview of the proposed project is given in fig.1. Proposed project has used existing SIP resources for irrigation in land. Sites were developed for each on 15 decimal lands contain 43.68 kWp Solar Panel Shades (85 feet x20 feet) the and a Pump house (10 feet x12 feet). In the pump house have an arrangement of 22 kW Solar Pump Inverter and the 18.5 kW submersible pump. Grid integration system has been incorporated with arrangement to utilize opportunity to import or export the surplus energy after the irrigation need to the grid. The project has proposed for goat rearing, fish farming activities at the pump site to make maximum use of its fallow land. As it has potential scopes to use the water from pump, project land and for excess clean energy uses for farming activities inside the Solar Irrigation Pump site which ensure the proper utilization of the project resources. A facility for Goat Farming between the fallow land (25 feet x 80 feet) between two Solar Panel Shade was developed. Also, a Fish farming pond was dug in the fallow land beside pump house. The project can be seen as an ideal profitable project as most of its ecosystem can be found within the project and the proposed compost pit facilitate waste management inside the project. Under the solar photovoltaic system, a house (80 feet x 20 feet) was built for goats in a scaffolding or rack system where at least 20 mother goats and 2 bucks can be reared (Fig. 3). Along with this, two compost pits (3.5 feet x 7 feet) were built for dumping the farming wastes and utilize it for fertilizer production from farm waste. A pond was dug between two sheds or beside pumphouse (depends on land availability) which approximate size 640 to 720 square feet for fisheries.

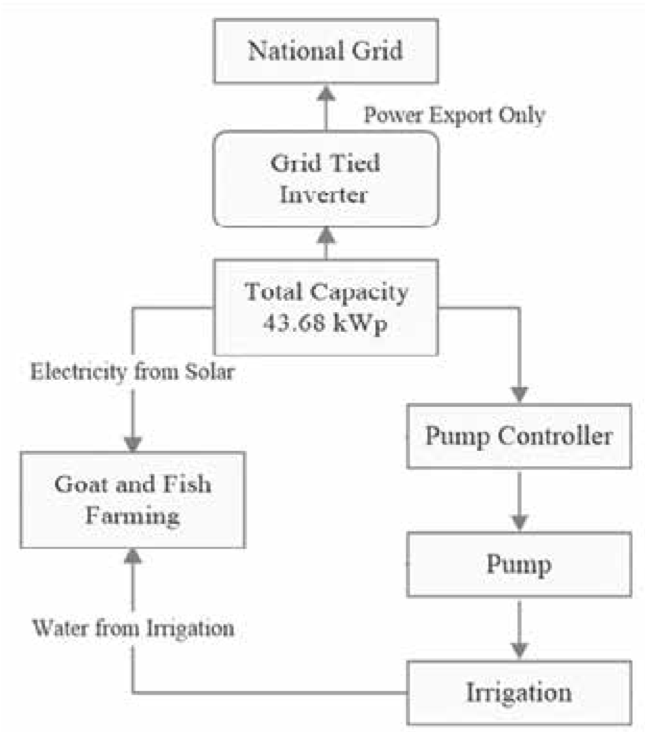

Fig. 1. Overview of the proposed project in solar irrigation pump site

Experimental Setup

Goat and Fish Farming

The farming intervention was initiated with building the fencing around the site for securing the premise, goat house construction, pond excavation and other activities like ensure the water and energy facility (Fig. 2). Black Bengal Goat, Fish (native an d carp fish) and fish feed were purchased for starting the farming. It takes 180 days for fish and goats to be profitable and after 180 days they will be sold at a higher price. An additional fencing was built around the SIP site for preventing unwanted external hazards. Water and air circulation and lighting equipment's were installed for the healthy farming. Twenty-two Black Bengal and 300 Catfish werepurchased for the experiment. Mother goat needs 6 months to get pregnant and the baby goats need at least 6 to 8 months for to be prepared for sell. Proper feeding and medication are required during this farming period. For fish, it takes three months for getting ready for selling. During this experiment, trained stuffs has monitored the operation and farming activities to ensure proper vaccination for goat and fish. The goat farming experiment has been started with ten young and healthy mother goats and 1 buck for each site. Young Black Bengal goats can breed single kid at the beginning but gradually it has started to breed multiple kids. As a result, it is expected to get ten or more kids at the beginning but from next year, breeding could increase up to 20 to 40 kids per year.

Fig. 2. Fish farming beside the pump house and goat farming under the panel structure

Table I. Goat farming data

No of Bucks	2
No of Mother Goat	20
Age at Maturity (Months)	9-10 months
Kidding interval (Months)	6-7 months
No. of Kidding's per year	minimum 4
Mortality (%) Adults	nil
Mortality (%) Kids	nil

Based on the data from Table I, one buck and ten mother goats were considered for each site. Mother goats reach maturity at 9-10 months of age. The kidding interval was 6-7 months, and each mother goat is expected to breed 4 kids per year. The mortality rate for both adults and the kid were nil during the experiment.

Table II. Fish farming data

Name of the species	Native and carp Fish
Stocking size	50 gm
Stocking density/pond	300
Culture period	5-6 months
Cost of seed	36 USD
Cost of feed	47 USD
Total feed required	124 kg
Target size at the time of harvest	600-700 gm
Survival rate	85%

Table II is about the culture of native and carp fish in two ponds located in Kulpala and Chuadanga and Poddopukur and Jhenaidah at a Solar Irrigation Pump site. Three hundred fish lings weighing 50 grams each was in each pond. Five to six months were considered to be the culture period. The seed and the initial cost of purchasing fish lings were both 36 USD at the time. 124 kg of feed were required over the course of the culture period, costing 47 USD. The target size of the fish at the time of harvest is 600-700 grams. About 85% of the fish are expected to survive throughout the growth period.

Fig. 3. Farming of black bengal goats and fish farming in the fallow land

Grid integration

Grid Instigation is referring to supply of additional energy to the grid after use of energy allotted for irrigation and farming or meet the irrigation needs. Technical solutions for integrating solar powered irrigation pumps into the national grid during off-season are devised based on whether the SIP already exists.Further renovation of the site was done to facilitate the energy import and export in the SIP site (Fig. 5).

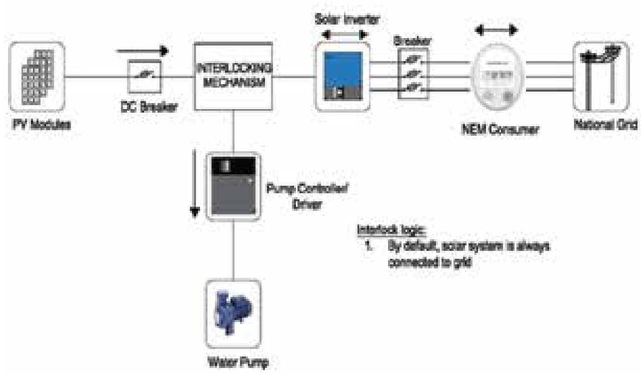

Fig. 4. The solar irrigation pump grid integration system

Fig. 5. Grid integration in operation

Based on the information in table III, the installed solar irrigation pump system had a total solar panel capacity of

Table III. Power generation calculation from each site

Solar Irrigation pump system	Solar panel (kWp)	Avg sunshine hour	Efficiency (%)	Generation in a day (KWp)
	43.68	3.5	85%	165
	Total generation in a year (365 Days)			60225
	Total use for irrigation (considering 200 day)			33000
	Surplus amount will be sold to utility company			

43.68 KWp with an average sunshine hour of 3.5 and an efficiency of 85%. From the system, estimated daily generation could be 165 KWp and annual generation of 60,225 KWp (365 days). The total use for irrigation is estimated to be 33,000 KWp, considering 200 days of operation. The surplus amount generated, which is not used for irrigation, is planned for selling it to the local utility company.

Results and discussion

Goat and fish farming

Information on the actual and anticipated production of fish and goat kids over a three-year period is shown in Table IV. Each cycle of production for goat kids lasts 6-7 months, and a minimum of 15 goat kids should be produced each cycle. In contrast to the projected production of 15 or more goat kids per production cycle, the actual production for the fiscal year 2021–2022 was 18 goat kids. The projected production for the fiscal years 2022-2023 and 2023-2024 is expected to increase by 35 or more goat kids because properly aged mother goats can have multiple kids at once. Each cycle of fish production lasts for six months, and more than 150 kg of fish are anticipated to be produced each cycle. In contrast to expectations, the actual production for the fiscal year 2021–2022 was 325 kg. Based on the actual production in FY 2021–2022, 340 kg is the projected production for the fiscal years 2022–2023 and 2023–2024.

Grid integration

To analyze the power production from the facilities, generation data of electricity from the solar photovoltaic system were recorded for three months with two weeks of interval.

The figure 6 depicts the kWh generation of a solar irrigation pump site in Kulpala, Chuadanga district. It displays generation data with a two-week frequency from August 28, 2022 to January 31, 2023. The highest generation was 1786 kWh on 06/11/2022. The highest generation days generate an average of 915 kWh. There were ten days with the highest average generation (915 kWh).

The graph depicts the electricity generated by a solar irrigation pump site in Poddopukur, Jheniadah district, from October 5, 2022 to January 31, 2023. For each date, it displays the generation in kilowatt-hours (kWh). During this time period, the highest generation was 1,007 kWh on November 23, 2022, and the lowest generation was 79 kWh on January 24, 2023. The highest generation's average generation is 929.14 kWh. The number of days with the highest average generation is nine.

Techno economic analysis

Table V shows the costs for a project with a 24-month duration. The project consists of several activities. The unit project cost for Construction of fencing, goat house, and compost pit for two units are required and resulting in a

Table IV. Production of goat kids and fish in FY 2021-2022

	Period	Production/ period	Actual production/year	Projected production/year	
			FY: 2021-2022	FY: 2022-2-23	FY: 2023-2024
Goat kid production	6-7 months	15+	18	35+	35+
Fish production	6 Months	150 kg+	325 kg	340 Kg	340 Kg

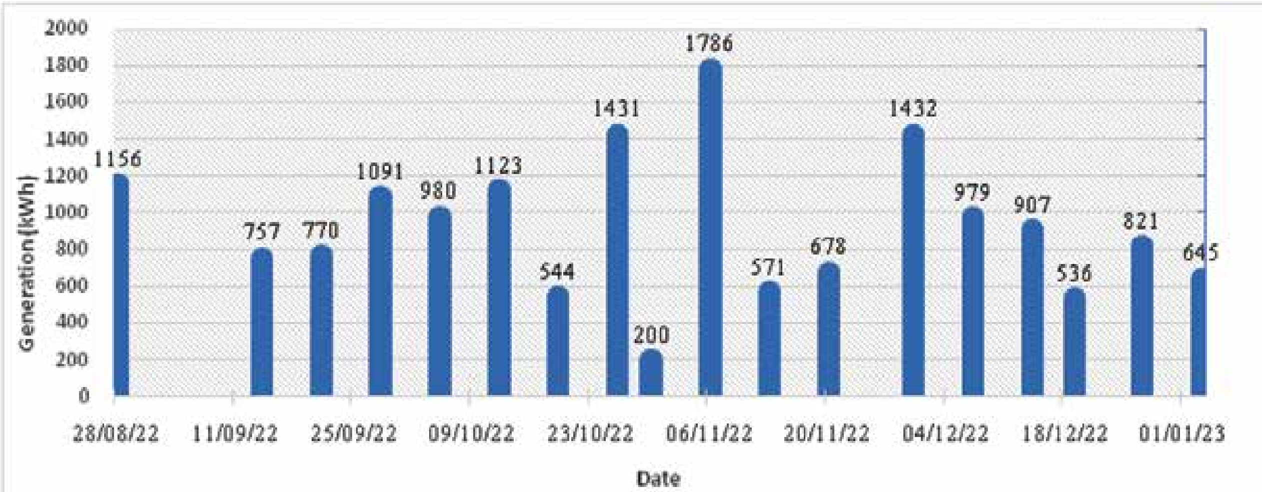

Fig. 6. Electricity generation from Kulpala, Chuadanga site

Fig. 7. Electricity generation from Poddopukur, Jhenaidah

Table V. Total project cost of the two number of projects in USD

Project Period	Activities	Unit project cost (USD)	Total project	Total project cost (USD)	Total project cost (BDT)
24 Months	Construction of fencing, goat house and compost pit	3080	2	6160	523600
	Pond excavation	588		1,176	99,960
	Electricity, water, air and lighting	1588		3,176	269,960
	Equipment purchases for farming	588		1,176	99,960
	Working capital for goat and fish	2985		5,970	507,960
	Purchase net metering equipment	5200		10,400	884,000
	Installation and operation on net metering system	588		1,176	99,960
	Total Amount	14617		29,234	2,484,890

Considering US $ = 85 BDT the total project cost in BDT total cost of $6160. The project cost for two pond excavation is $1176. The project cost for electricity, water, air and lighting is required for 2 units is $3176. Equipment purchases for 2 units resulting in a total project cost of $1176. Working capital for goat and fish farming for 2 units are required, resulting in a total project cost of $5970. Purchasing net metering equipment for 2 units, accumulated in a total project cost of $10400. The unit project cost for installation and operation of the net metering system is $588, and 2 units are required, resulting in a total project cost of $1176. The total amount in US dollars for the entire project is $29234.

Figure 8 shows the cost breakdown for different activities in the project. The activities are Goat Farming Cost, Fish Farming Cost, and Net metering. The Total Cost column shows the cost incurred for each activity and the Percentage column shows the relative contribution of each activity to the total project cost. The Goat Farming Cost accounts for 21.07% of the total project cost, while Fish Farming Cost accounts for 4.02% of the total project cost. Common Expenditure for goat and fish farming accounts for 35.33% of the total project cost and Net metering accounts for 39.60% of the total project cost.

Figure 9 shows the revenue generated from different sources for three fiscal years, FY 2021-2022, FY 2022-2023, and FY 2023-2024. The first column represents the fiscal year, while the subsequent columns represent the revenue generated from Goat Sale, Compost Sale, Fish Sale, and Net-metering

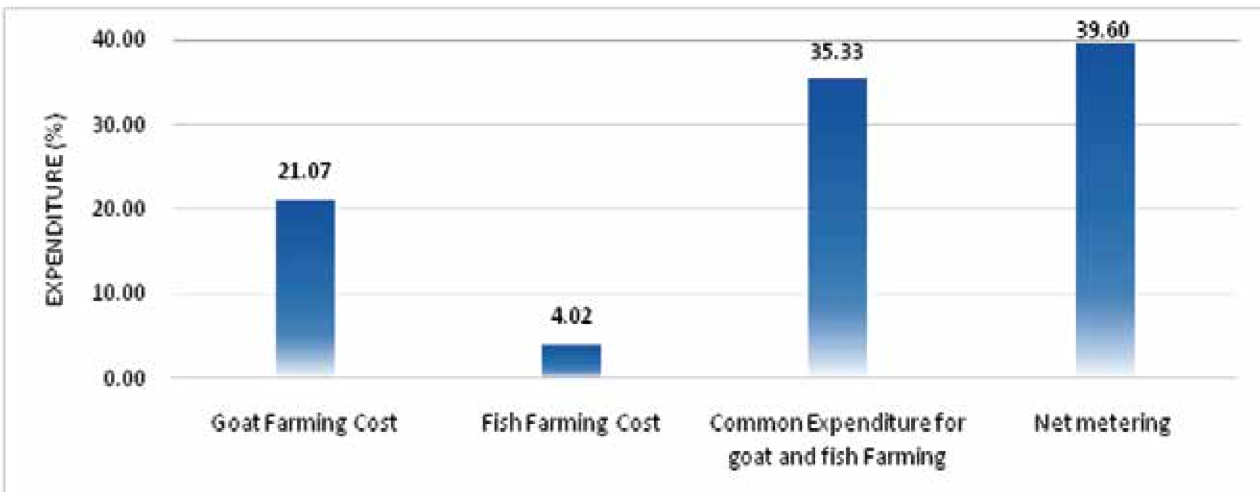

Fig. 8. Activity wise expenditure in percentage

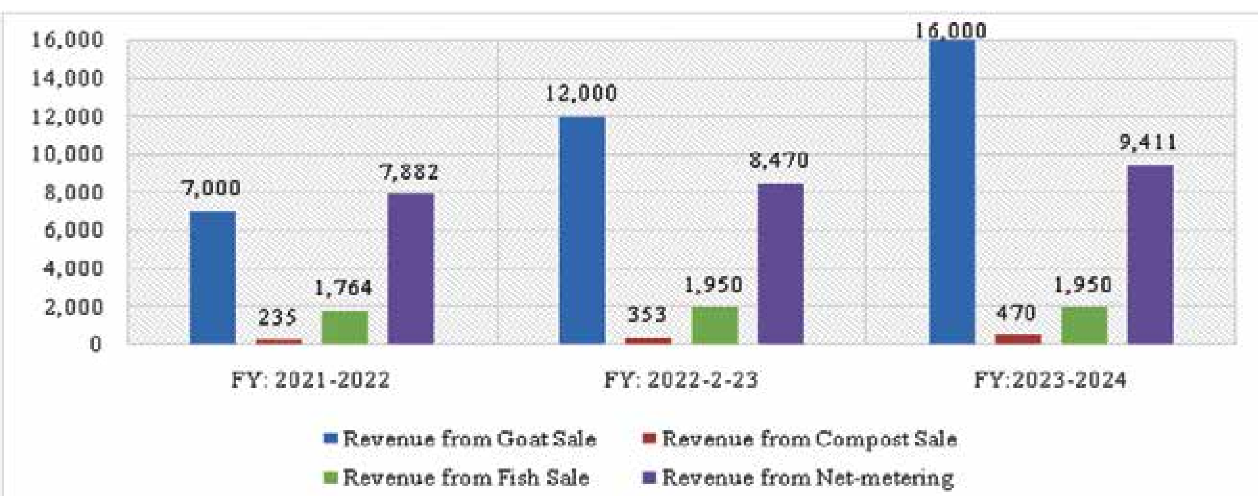

Fig. 9. Fiscal year wise revenue generated from each activity

respectively. The actual revenue generated in the FY 2021-2022 was $7,000 from Goat Sale, $235 from Compost Sale, $1,764 from Fish Sale, and $7,882 from Net-metering, making a total revenue of $16,881. The projected revenue for FY 2022-2023 shows an increase in the revenue generated from Goat Sale, Compost Sale, and Fish Sale and the revenue from Net-metering. The revenue from Goat Sale is estimated to increase from 7,000 to 12,000, from Compost Sale from 235 to 353, and from Fish Sale from 1,764 to 1,950 and revenue from net metering was $8470. Similarly, for FY 2023-2024, the projected revenue was expected to increase in the revenue generated from Goat Sale, Compost Sale, and Fish Sale. The revenue from Goat Sale is estimated to increase from $12,000 to $16,000, from Compost Sale from $353 to $470, and from Fish Sale remains constant at $1,950. The revenue from Net-metering was estimated $9,411.

Figure 10 shows the total revenue generated and expected revenue generation from different sources for three financial years. The revenue generated from goat sale is 35,000 USD. The revenue generated from compost sale is 1,058 USD. The revenue generated from fish sale is 5,664 USD. And, the revenue generated from net-metering is 25,763 USD. The total revenue generated from all sources is 67,485 USD.

Figure 11 shows the cost of goods sold for different items (Goat, Fish, and Net Metering) in three different fiscal years: FY 2021-2022, FY 2022-2023, and FY 2023-2024. The cost of goods sold represents the direct expenses associated with

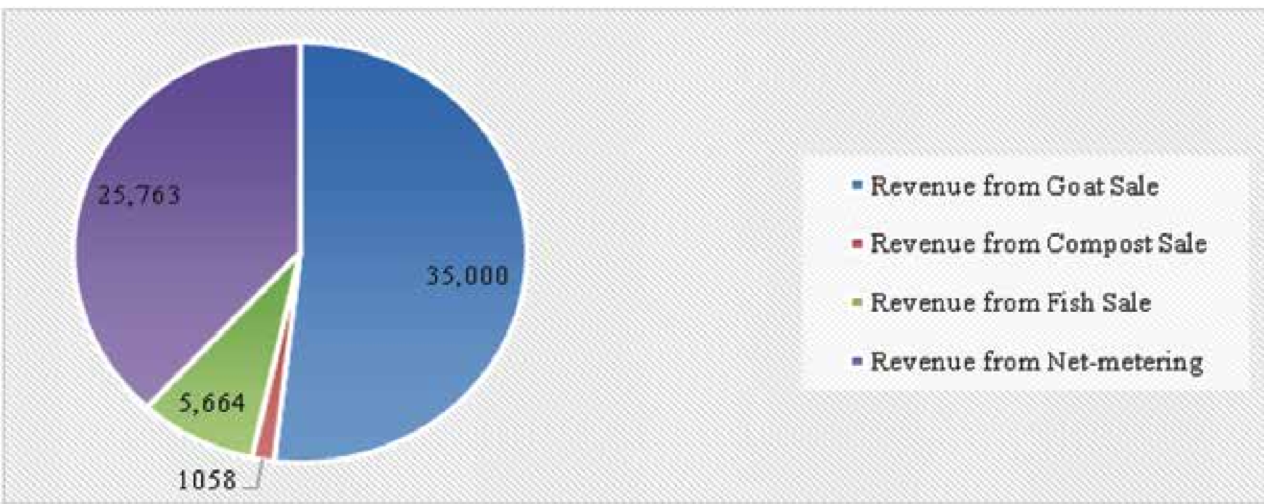

Fig. 10. Activity wise generated total Revenue

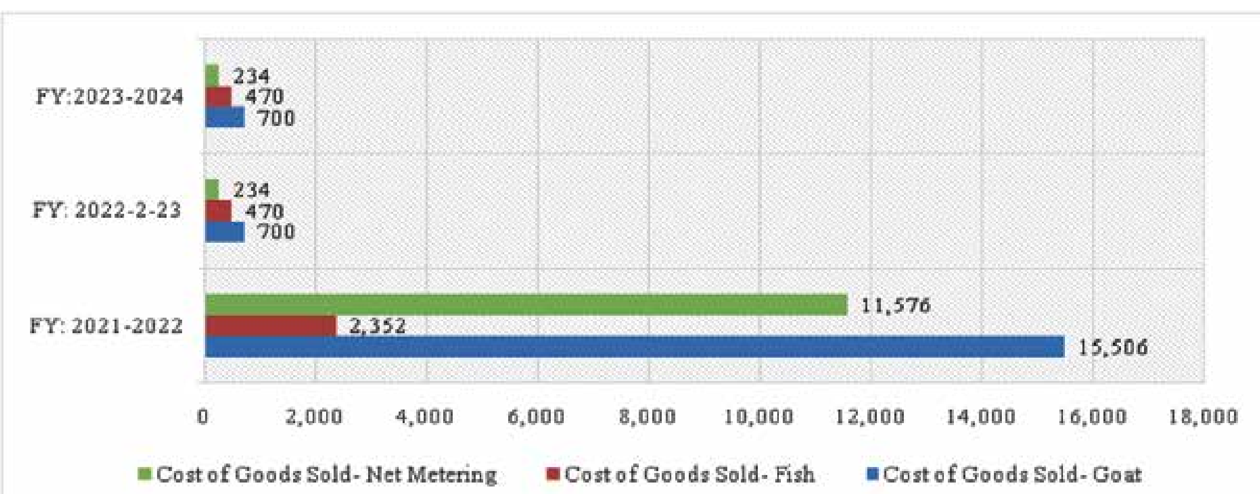

Fig. 11. Cost of goods sold in fiscal years

producing the goods that were sold during a specific period. In FY 2021-2022, the cost of goods sold for goat was $15,506, for fish was $2,352, and for net metering was $11,576. In FY 2022-2023, the cost of goods sold for goat reduced to $700, for fish was $470, and for net metering was $234. In FY 2023-2024, the cost of goods sold remained the same as FY 2022-2023 for goat, fish and net metering, $700, $470 and $234 respectively.

expectations of reaching 35 or more kids per year in the coming years. Similarly, the fish farming cycle yielded 325 kg of fish in the first year, with a projected increase to 340 kg in the subsequent years. The grid integration system allowed for the import and export of surplus energy to the national grid. The electricity generation data showed significant potential, with the highest average daily generation reaching 915 kWh in one site and 929.14 kWh in the other site. The

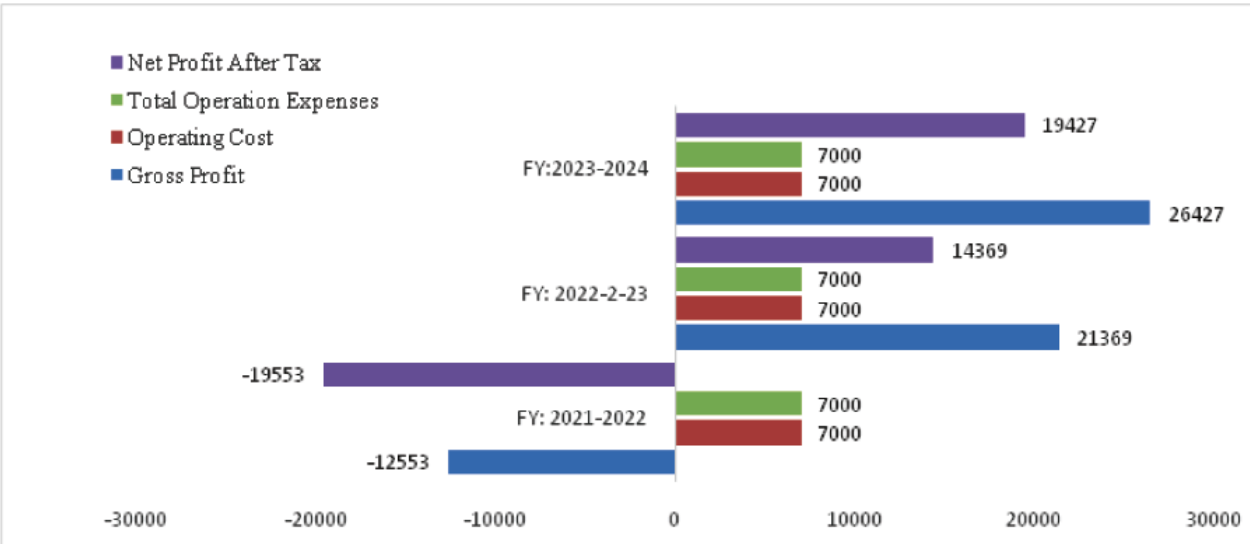

Fig. 12. The financial performance of the experiment for three fiscal years

Figure 12 shows the financial performance of a business for three fiscal years: 2021-2022, 2022-2023, and 2023-2024. In FY 2021-2022, the Gross Profit was negative (-12553 USD) indicating that the cost of goods sold was more than the revenue earned. This resulted in a Net Profit After Tax of -19553 USD. In the next two fiscal years (FY 2022-2023 and FY 2023-2024), the Gross Profit increased to 21369 and 26427 respectively. This resulted in a Net Profit After Tax of $14369 and $19427 respectively, indicating that the business made a profit of $14369 and $19427 in those fiscal years. The operating cost represents the expenses incurred to run the business operations were constant across all three financial years and is equal to $7,000.

Conclusion

The pilot study conducted in Chuadanga and Jhenaidah districts demonstrated the potential of combining solar energy generation with agricultural activities such as goat rearing and fish farming. The goat farming and fish farming activities showed positive outcomes, with an increase in production projected over the three-year period. The goat farming cycle produced 18 goat kids in the first year, with

techno-economic analysis provided insights into the project's cost and revenue generation. The project cost was estimated at $29,234, with the majority of the expenses allocated to net metering. The revenue generated from goat sales, compost sales, fish sales, and net metering showed steady growth over the fiscal years, reaching a total revenue of $67,485. Overall, the integrated farming model demonstrated its potential for sustainable energy production, agricultural diversification, and revenue generation. It presents an innovative solution to address the challenges faced by the energy and agricultural sectors in Bangladesh, contributing to the country's sustainable development goals.

References

Andrew AC, Higgins CW, Smallman MA, Graham M and Ates S (2021), Herbage Yield,Lamb Growth and Foraging Behavior in Agrivoltaic Production System, *Frontiers in Sustainable Food Systems* **5:** https://-doi.org/10.3389/fsufs.2021.659175

Barron-Gafford GA, Pavao-Zuckerman MA, Minor RL, Sutter LF, Barnett-Moreno I, Blackett DT, Thompson

M, Dimond K, Gerlak AK, Nabhan GP and Macknick JE (2019), Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands, *Nature Sustainability* **2**(9): 848-855. https://doi.org/10.1038/s41893-019-0364-5

BPDB (2022), *Bangladesh Power Development Board Annual Report-2021*. http://bd.bpdb.gov.bd/bpdb/new_annual_reports

Dupraz C, Marrou H, Talbot G, Dufour L, Nogier A and Ferard Y (2011), Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes, *Renewable Energy* **36**(10): 2725-2732. https://doi.org/10. 1016/j. renene. 2011. 03.005

Food and Agriculture Organization (FAO) (2017), *The future of food and agriculture*. https://www.fao.org/3/i6583e/I6583E.pdf

SREDA (2021), *Renewable Energy Potential*. Www.sreda.gov.bd. http://www. sreda. gov.bd/ site/page/e2e11971-0e8e-4ef7-b764-f5e09d21f73b/-

Walston LJ, Li Y, Hartmann HM, Macknick J, Hanson A, Nootenboom C, Lonsdorf E and Hellmann J (2021), Modeling the ecosystem services of native vegetation management practices at solar energy facilities in the Midwestern United States, *Ecosystem Services* **47**: 101227. https://doi.org/10.1016/j.ecoser.2020.101227

Weselek A, Ehmann A, Zikeli S, Lewandowski I, Schindele S and Högy P (2019), Agrophotovoltaic systems: applications, challenges, and opportunities. A review, *Agronomy for Sustainable Development* **39**(4): https://-doi.org/10.1007/s13593-019-0581-3

World Bank (2021), *World Development Report 2021*. World Bank. https://www.worldbank.org/en/publication/wdr2021

Worldometer (2023), Worldometers.info. https://www.worldometers.info/world-population/bangladesh-population/