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SUSTAINABLE INTEGRATED SYSTEM FOR RURAL DEVELOPMENT: A CASE STUDY

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Abstract. India is one of the largest countries in the world, with a population mainly living in villages and primarily engaged in dairy activities along with agriculture. Despite being the largest milk-producing nation, lives of local farmers are challenging due to the lack of access to technology in rural areas. This study aims to develop an integrated system that can solve the problems faced by farmers by utilizing locally available resources. Due to the time lag between milking and storage, milk spoilage is more likely to occur in remote areas. Immediate pasteurization and storage facilities are required. Heating and refrigeration are essential for pasteurization. In India, most villages face power shortages, so biomass heat is suitable for pasteurizing milk. A steam jet refrigeration system is also proposed as it runs with waste biomass for chilling milk. Steam required for both heating and chilling milk is generated in the same biomass-fired boiler. Also, make-up water requirements in the boiler are fulfilled using a rainwater harvesting system. In a conventional dairy plant, a cooling tower is used to supply condensate water required in the condenser. Here this water requirement is fulfilled using a bore well. Subsequently, this water is stored in the irrigation pond to cool it by natural cooling through surface evaporation, making the water suitable for irrigation purposes. Also, the payback period of this system is estimated to be less than six months. Looking at the multiple benefits, this integrated system will further facilitate in achieving sustainable development goals through rural development by 2030.

Keywords: rural development; milk pasteurization; carbon neutral; water purification

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1. Introduction

Livestock, dairy activities, and agriculture have continued to be an integral part of human life since the beginning of civilization. These activities contribute to food baskets and maintaining the ecological balance in India and play an essential role in the country's overall socio-economic development. They also play an important role in creating jobs for rural areas, especially landless, small, disadvantaged farmers and women, and providing affordable and nutritious food to millions. India's dairy sector has grown significantly in the last few years. According to the Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, the country ranks first among the world's milk producers, achieving an annual production of 198.4 million tonnes in 2019-2020, compared to 187.75 million tonnes in 2018, showing a growth rate of 5.68%, as shown in Figure1. Further, the global milk production increased by 1.43%, from 884 million tonnes in 2019 to 860.1 million tonnes in 2020 (Annual Report, Government of India, 2021).

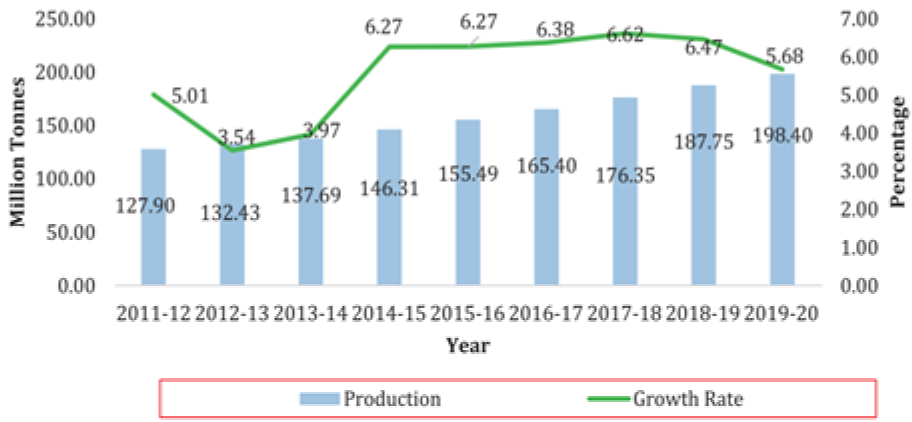

Figure 1. Milk production with corresponding Annual Growth Rate in India (Annual Report, Government of India, 2021).

Due to its enormous nutritional value, milk is the most vital food. Cow's milk has an average composition of 87.7% water, 3.4 percent fat, 4.7 percent sugar, 3.4 percent protein, and 0.7 percent ash and this 1/6 ash is calcium (Pandey & Gupta, 2013). On average, India's milk requirements are around 200 million litres per day. Moreover, this requirement is getting fulfilled by farmers in the villages as they own about 95% of the milk-producing cows in the country. The source of raw milk for processing in these plants is from rural areas. The nearest milk processing factory is often far away in many villages. The time it takes for milk to arrive at the processing facility due to a lack of suitable and rapid means of transportation is very long (Panchal & Patel, 2016). When it comes to milk, bacteria are active from the beginning. Delayed milk processing increases acidity and makes it unsuitable for milk processing. Hence, pasteurization is needed. Pasteurization is a mild heat treatment process designed to eliminate harmful pathogenic and spoilage microorganisms from milk to improve its quality and shelf life. Heating is essential for pasteurization. In India, rural areas have scarce electricity, so it would be a priority to look for some alternative options like solar heat or biomass (Panchal & Patel, 2016). In villages, biomass is readily available as a waste product from the agricultural farm. It can be considered as a suitable option. Biomass has generally been a significant energy source for the rural areas, so it could be an appropriate option. It is renewable, widespread, carbon-neutral, and capable of generating significant employment in rural areas. Biomass can also provide reliable energy, which currently contributes to more than 32% of the nation's total primary energy supply, with more than 70% of the people relying on it to meet their energy demands (Annual Report, Government of India, 2021). Along with heating, cooling is equally important to complete the pasteurization process. It requires storing the milk up to 5 ˚C until it gets sold to ensure longer shelf life. For this purpose, a suitable refrigeration

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system is needed. As mentioned above, lack of electricity is one of the major constraints in the village; hence, steam jet refrigeration can be a possible option. This system simply runs on low-grade energy like biomass readily available in the villages from farm waste (Sriveerakul, Aphornratana & Chunnanond, 2007; Thongtipa, Ruangtrakoona, & Aphornratana, 2014). The steam jet refrigeration system is easy to operate and doesn't require high maintenance.

2. Current status of dairy and horticulture facilities in rural areas

In India, milk production employs around 80 million rural households, with many smallholders, marginal farmers, and landless people. However, for milk processing, the farmers have to encounter many challenges due to lack of proper technology, knowledge, and resources. Since 1991, when the era of industrial licensing reforms began, private companies have had remarkable growth in building their capacity to process milk and milk derivatives. They have made significant investments in the dairy sector, creating capabilities that exceed the combined capacity of dairy cooperatives and state dairy over the last two decades. These private companies are much more prominent than some cooperative dairy farms and have excellent growth potential. The private sector operates on purely commercial principles to maximize profits, so its social responsibility for farmers' development is seriously undermined. Private companies prefer to procure milk through vendors, and the farmers do not get a fair price for their products. In India, about 46% of the milk produced is consumed at the farm level or sold to non-producers in rural areas, and the remaining 54% is sold in the organized and unorganized sectors. The organized sector consists of governments, producer-owned institutions (dairy cooperatives and producer companies), and private sector stakeholders to provide a fair and transparent system of village-level milk collection throughout the year. In most cases, the unorganized/informal sector includes local milk vendors, contractors, etc. Generally, no one fixed price of milk is paid to producers, as it depends on the situation. In competitive and formal sector milk procurement, prices are usually high and, at the same time, do not offer reward prices to farmers that do not have access to the organized sector (Annual Report, Government of India, 2021).

Like dairy, agriculture and allied activities are also crucial to the Indian economy. This sector employs 54.6 percent of the total workforce, as per Census 2011, and accounts for 17.8 percent of the country's Gross Value Added (GVA) in 2019-20, as shown below in Figure 2 (Annual report, Government of India, 2021).

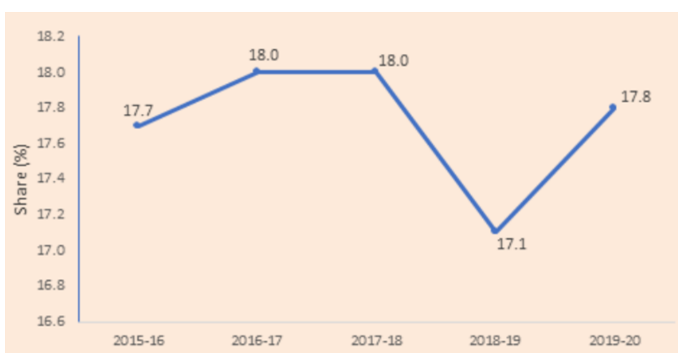

Figure 2. Share of GVA of agriculture and allied sector in GVA of total economy (Annual report, Government of India, 2021).

Considering the significance of agriculture and horticulture, the Indian government has taken many initiatives to ensure its long-term development. But these initiatives are generally more beneficial for big farmers.

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Smallholders and marginal farmers still have to suffer a lot because, in the absence of storage facilities, they are bound to sell their products to vendors on a daily basis. Otherwise, it will get spoiled and not paid a fair price.
In rural areas, the health conditions of farmers are not that good because they are still dependent on untreated tube-well water for drinking and other household work. Rural people can't afford water filters that are available in the market. Underground water is not very good for health as its mineral contents vary depending upon the area. And in some cases, a few minerals like arsenic are present in excess which may cause serious health concerns.

Initiatives Taken By Government of India to Support Dairy Sector

- Under the initiative for self-reliance India (Atma Nirbhar Bharat Abhiyan), the government of India has launched a package worth 150 billion Indian rupee named "Animal Husbandry Infrastructure Development Fund" (AHIDF) for developing new dairy structures and supporting the existing plants in the rural areas.
- Another initiative named "e-GOPALA" has also been launched to provide market access to the farmers to buy high-quality germplasm. In addition, all the information related to animal food and vaccination is available with the help of information technology.
- The government has also recently started a special drive with the association of "Department of Animal Husbandry and Dairying" and "Department of Financial Services" to provide Kisan Credit Card (KCC) to 15 million dairy farmers to provide financial assistance to them.

3. Literature review

In a country like India, almost 55% of its workforce is primarily engaged in agricultural and allied activities (Annual report, Government of India, 2021) for their livelihood. This sector has a direct impact on the lives of millions of people. Many research studies have been carried out for agriculture and rural development in the Indian context. However, the more relevant studies with regard to this research are briefly presented here.

Rural development plays a very important role in the growth of any country. In this context, Rao (2019) has studied the challenges faced by rural people, like housing issues, infrastructure, and transportation. The main aim of his study was to discuss the various government policies for rural development and how effectively those policies can be implemented for the development of rural areas. Also (Takhumova, 2019) has discussed about the role of rural development in the economic growth of the country and its contribution in GDP. In a research study (Nedumaran & Manida, 2020) have discussed about the importance of agriculture in the growth of developing nation. They have discussed about the broad spectrum related to agriculture and economy of a country.

In the study by Prakash and Henham (2014) for Parag Dairy plant at Allahabad, Uttar Pradesh, India, they have proposed decentralized tri-generation system as a replacement to the conventional grid electricity based system. They have proposed "Combined Cooling and Heating Power (CCHP)" systems with three different configurations. All the calculations were based on the plant's primary energy consumption criteria. They concluded that proposed systems had multiple benefits for the processing plant and could make the plant independent of grid electricity supply.

The study of Dobrowsky et al. (2015) for milk pasteurization system coupled with rainwater harvesting system aimed to reduce the microbiological load in the water harvested through the rainwater harvesting technique and to analyse the change in the chemical composition of the harvested water so that large quantity of portable water can be produced from the system.

They have performed experiments in different temperature ranges to achieve the above objective and found that cat-ions were within the limits of drinking water except for a few, like iron and aluminium. Also, the growth of bacteria is below the detection level at higher pasteurization temperatures. To produce large amount of portable water from the mentioned technique, they suggested that the storage tank for milk should be of some alternative material different from stainless steel for the coupled system to work efficiently.

A study by Wayua et al. (2012) for milk pasteurization in a dry area like Kenya was done using solar energy. They have conducted the experiment using a cylindrical flat plate solar collector made from glass fibre of 1.5mm thickness. In this study, water was boiled using solar heat, and then they used this water for milk pasteurization. After conducting the experiment, it was concluded that this type of small-scale pasteurization unit is beneficial in the arid areas where dairy is an essential source of income for the people.

Delay in milking and its pasteurization in the rural areas due to lack of proper transportation facilities and electricity leads to milk spoilage. Sur et al. (2020) conducted an experiment using a parabolic solar collector for milk pasteurization. For milk chilling, they had used a vapour absorption refrigeration system that runs on low-grade energy which is easily accessible in the villages. During heating and storing milk at a low temperature, stainless steel (SS316) was selected as the material for the tank and piping so that it would not react with milk. After conducting the experiment, they concluded that solar heat-driven systems had several benefits for the rural areas.

Many research studies have been conducted in the field of milk pasteurization through solar heat. In this context, Panchal et al. (2020) reviewed the various research works done by other research scholars all across the globe for milk pasteurization using solar panels for rural areas and its feasibility. After analysis, they concluded that solar heat had a significant impact on the milk pasteurization technique. It is capable of reducing the cost of pasteurization and does not contribute to global warming.

In a study by Reddy and Verma (2004), heating and cooling are equally important for dairy activities. Generally, medium hot or cold steam or air is required, which can be easily obtained using solar heat. They have also discussed the feasibility of utilizing solar heat and showed that a significant amount of money can be saved using this technique. A study by (Dhankhar, 2014) on refrigeration found that refrigeration plays a significant role in food preservation. She has explained the basic refrigeration cycle and all the processes involved in it. She has also demonstrated the commercial use of refrigeration in the dairy industry.

A steam jet refrigeration system has been developed and tested by Thongtip et al. (2013) for Thailand. They experimented in ambient conditions, and geometries were kept constant throughout. From the experiment, maximum coefficient of performance was found to be 0.5. Yapici (2008) has designed and manufactured the experimental setup for a steam jet unit. He developed a novel ejector based on constant area and conducted the experiment in a wide range of operations. He had concluded that this system had coefficient of performance of 0.39 when the ejector was kept at the optimum area ratio of 9.97.

Presently water scarcity and energy availability are two major concerns. Increasing demand for energy increases its cost, and burning fossil fuels leads to global warming. Hence renewable energy can be a suitable option for this. Solar energy can be one option among them. A study by Gugulothu et al. (2015) discussed the challenges associated with harnessing solar energy as it is intermittent. They have proposed Thermal Energy Storage, which can be used for this purpose.

A study by Levy et al. (2008) have discussed water vapour recovery from flue gas using heat exchangers from a coal-fired plant. They have performed pilot-scale heat transfer test for established the relation between vapours. An experimental setup, has been used determined the amount of water vapour from flue gas that can be recovered.

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As exhaust from the boiler is generally at a higher temperature, heat recovery from this exhaust can be made using heat exchangers. In this context, Li et al. (2016) have proposed a technique to recover the waste heat using an absorption heat exchanger in a gas co-generation plant. From the experimental analysis of this system, it has been found that waste heat recovery increases the plant efficiency significantly and also discussed the system's other benefits.

Distillation of water is one of the oldest techniques used to remove contaminants. A study by Kamrin (1990) have discussed the various steps involved in the distillation process. They also mentioned the main problems associated with contaminated water. Also, Lockett and Resetarits (2003), have examined the chemical processes that can be used to distill water in laboratories.

Prakash and Henham (2011) have studied small scale multi-generation systems and validated the results. They found that if a single generation plant gets converted into cogeneration plants or tri-generation plants, they can provide cooling or heating effects along with electricity generation. They concluded that it can increase the efficiency by 19% and the plant's carbon reduction potential up to 50%. By setting up this plant in the coastal areas, seawater cooling further increases the plant efficiency, and salt can be produced as a by-product of the system.

On a macro-level, Munasinghe (2019) studied three pillars of sustainable development i.e. social, economic, and environmental. In this study, he focuses on poverty, sickness, hunger, inequality, etc in addition to macro-economic growth, resource depletion, and environmental pollution. He has discussed an empirical approach to sustainable development through the concept of “Sustainomics”.

Prakash (2013) proposed a comprehensive development indicator HPI i.e. “Holistic Progress Index” as an alternative to conventional GDP. In his research, he has presented an original approach to its quantitative evaluation. The major parameters related to HPI and its evaluation methodology has been discussed. From this study, he has concluded that HPI is much more comprehensive than GDP and may lead to peaceful, sustainable growth with general happiness.

A study by Prakash and Garg (2019) presented a new approach for measuring the development of any country. They have proposed “Composite development Index” (CDI) in place of “Human development Index”. In their paper they have discussed about all the aspects of sustainable development including peace and happiness. They have concluded that CDI is more comprehensive than HDI and high CDI may pave the way to sustainable development of a country.

From the literature review, it has been found that in rural areas where there is a scarcity of electricity; solar and biomass are the best possible renewable energy resources that can be used for power generation. It is also evident that an integrated plant has better efficiency and output as compared to single-generation plants. In this study, an integrated multi-generation plant has been proposed for milk pasteurization, and biomass is considered as an option for heat generation. The research methodology adopted for the successful completion of this study is mentioned below in the Figure 3.

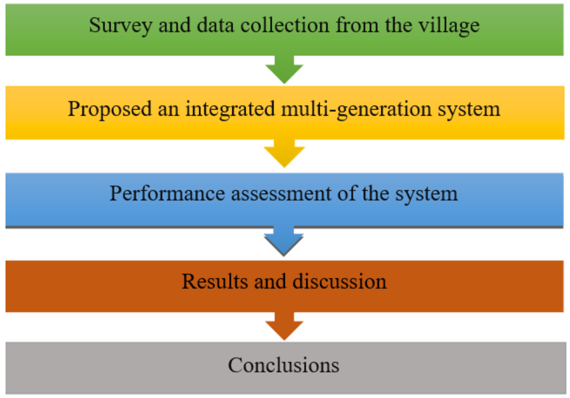

Figure 3. Research Methodology

4. Proposed integrated system

The main goal of this study is to develop an integrated small-scale multi-generation system for rural areas, lacking infrastructural facilities and advanced technology. The proposed system's schematic diagram is illustrated in Figure 4.

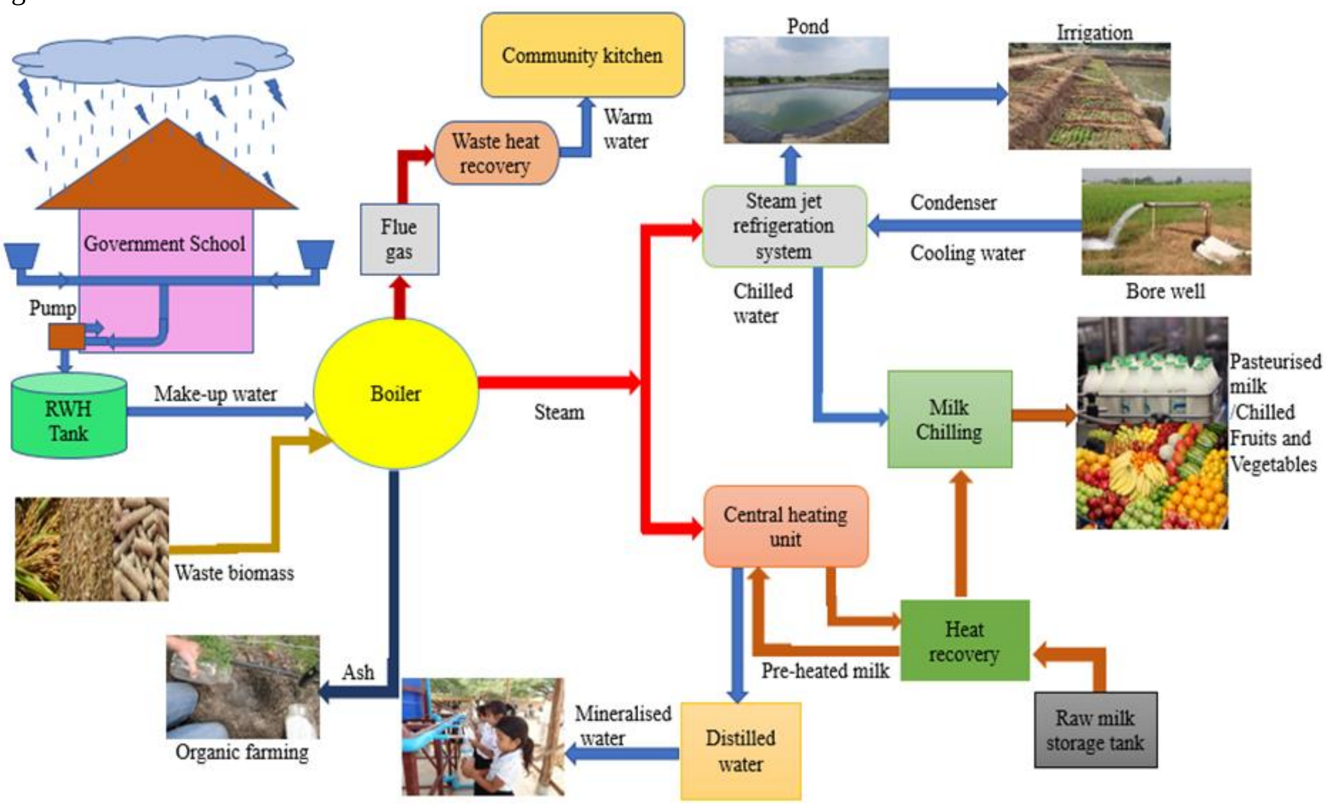

Figure 4. Illustration of proposed system layout

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As demonstrated in the diagram, an integrated small scale system that is capable of pasteurization of milk, distillation of water, generation of warm water for the community kitchen, as well as ash from burning of biomass which is helpful for organic farming. Further, it will help in farm irrigation using condenser cooling water, which is naturally cooled through surface evaporation in the water storage pond.

Working Principle

In this proposed system, a waste bio-mass-driven boiler has been used to generate steam. This generated steam from the boiler is used both for heating and chilling of milk through a steam driven system. A "High Temperature Short Time" pasteurization process in which milk is heated at 73^0C for 15 – 20 seconds is used here for the pasteurization of milk. The raw milk from the farmer is sent to the heat exchanger where it gets preheated, and then this milk is sent to the central heating unit where it is heated for the above mentioned time and temperature. A heat exchanger is a device used to transfer heat from hot fluid to cold fluid. After heating this milk, it needs to be stored in a cold chamber until delivered to the customers. A steam jet refrigeration system has been proposed for the chilling of milk, which works on the principle of boiling liquid at a lower temperature by reducing the pressure on its surface.

This system entirely runs on low-grade energy, and here this energy is generated using biomass which is renewable in nature and readily available in the villages from agricultural waste. In a steam jet refrigeration unit, condenser is the bulkiest component of the system. It requires a large amount of cooling water. This water requirement will be fulfilled using an existing bore well. After being used for cooling purposes, this water will be stored in the irrigation pond where it gets cooled through natural surface cooling, and then it may be used for irrigation on the nearby farms.

The water of the bore well is not pure, and it can cause erosion in the boiler. Hence, water treatment is needed, which requires significant investment. As an economical alternative, rainwater is stored here through rainwater harvesting. In rainwater harvesting, water is collected on the roof-top of a government school building and then transferred through a conveyor pipe system to a storage tank.

These storage tanks are usually situated above, middle, or below the ground as required. This system is simple and requires low maintenance. Water from this storage tank can be easily used in the boiler as it is pure and will not severely impact the boiler operation.

The government school building used for water harvesting is supplied with warm water in the community kitchen of the school by waste heat recovery from flue gas.

This system will also supply treated mineralized water to the school students. After heating the milk, condensed steam will be re-circulated back to the boiler, and some water is bled off from it, which after cooling and addition of minerals lacking in that area, can be used for drinking.

Further, burning biomass for steam production in the boiler will produce ash. This ash can be helpful in organic farming, e.g. for some of the vegetables like onions. Hence it is evident that this small-scale integrated system has many advantages.

5. Performance assessment of the proposed system

5.1 The case study

The case study involved a survey and data collection from a small village Gauspur Sarsouna which comes under the Samastipur district of Bihar, India (shown in Figure 5 and Figure 6). This village has the potential to grow but

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lacks in access to technology. The data shown below in the Table1 is used to check the technical feasibility of the proposed system.

As explained above, an integrated multi-generation system has been proposed for rural areas. A case study has been carried out for the performance assessment of this proposed system. Results are presented below.

Figure 5. Rural area of Bihar, India

Figure 6. Google earth image of Gauspur Sarsouna, Bihar, India

Table 1. Statistical data of the village

State	Bihar
District	Samastipur
Village	Gauspur Sarsouna
Population	20,000
Households	4,000
Cattle	2,400
Average milk production	5 litres/cattle
Total milk production	12,000 litres/day

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The proposed system is required to heat 6000 kg/hr of milk per hour in the heat exchanger for pasteurization, where 127 kg/hr of 1800C steam is needed. Further, for chilling the same milk through a steam jet refrigeration system, an additional 232 kg/hr of steam is required in the flash chamber of it. Flash chamber is an insulated container that separates liquids and vapour. Therefore bio-mass-driven boiler needs to produce a total of 456 kg/hr of steam, considering the losses that may occur in the boiler. Calculation of steam jet refrigeration system has been done considering its coefficient of performance as 0.5. Coefficient of performance is used to define the energy requirement of a system for achieving the desired output. The total cooling water needed in the condenser to complete the refrigeration process is 24507 kg/hr. This requirement is getting fulfilled using a bore-well, and subsequently, this water will be used for irrigation after getting it cooled through natural surface cooling in storage ponds.

During heating and storing milk at a low temperature, stainless steel (SS316) was selected as the material for the tank and piping so that it would not react with milk. Biomass generally has a calorific value of 15- 22 MJ/kg. Here the agricultural waste that is available for biomass production is having average calorific value of 17.5 MJ/kg, and 135 kg/hr of this biomass is required to burn, assuming boiler efficiency as 80 %. Flue gas or exhaust gas released through the chimney of the boiler is generally at a higher temperature of about 1400C. By passing it through a heat recovery system, 10 % of energy can be recovered from it, which has been utilized to heat the water, and this warm water at a temperature of 440C is supplied to the community kitchen of the government school.

This government school building has a rooftop area of 1780m^2. Assuming annual rainfall in this village as 1186 mm and considering all other factors, it has been estimated that a total of 13.51*10^5 L of rainwater can be harvested.

Table 2. Inputs and outputs of the Integrated System

Inputs	Outputs
Raw milk = 12000 litres/day	Pasteurized milk = 12000 litres/day
Waste biomass burned = 135 kg/hr	Ash generated = 6.75 kg/hr
Rainwater harvested water = 13.51 * 10^5 litres/annum	Treated drinking water = 30 kg/hr
Bore-well water = 22507 kg/hr	Warm water in the community kitchen = 132 kg/hr

After a complete assessment of the proposed integrated system, following outputs are obtained as presented in Table 2 for the given inputs. On average, 6,000 litres of milk can be pasteurized per hour from the system and 12,000 litres daily. Also, 6.75 kg of ash will be produced per hour from the system, considering that 5% of the biomass will get converted into ash. 30 kilograms per hour of water for drinking and 132 kg per hour of warm water for the community kitchen can also be obtained from the system.

5.2 Cost analysis

It is essential to analyse the cost involved in the proposed system to determine its economic feasibility. In Table 3, costs of various equipment used in the integrated multi-generation system is shown. With the help of this table, payback period of the system has been estimated.

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Table 3. Cost of various equipment of the system in Indian Rupees

Rainwater storage system	12,00,000
Biomass- driven boiler and auxiliaries	10,00,000
Steam jet refrigeration system and its auxiliaries	6,00,000
Heat exchanger	6,00,000
Auxiliary equipment (e.g. pumps etc.)	3,00,000
Set-up installation cost	5,00,000
Approximate total cost of proposed system	42,00,000

Including all the expenses, the profit per litre of pasteurized milk is assumed as Rs. 5. Therefore total profit made per day is Rs. 60,000.

$$\text{Payback period} = \frac{\text{Investment}}{\text{Profit}} = \frac{4200000}{60000} \approx 70 \text{ days.}$$

Taking into account the uncertainties in cost estimates, it is evident from the above result that payback period for the proposed integrated system is less than six months.

Conclusions and future scope

In this rural development study, a small village, Gauspur Sarsouna, in the Samastipur district of Bihar, India, has been selected. Based on technical analysis of the proposed integrated system for this village, following conclusions are derived.

Through an integrated small-scale multi-generation system, milk pasteurization is feasible using a biomass-driven boiler, and for chilling of milk, a steam jet refrigeration system is found as a suitable option. From this system, mineralized water can be produced and supplied to school students, which will improve their health conditions. Warm water obtained through the waste heat recovery of flue gas can be used in the government school's community kitchen for cleaning utensils. For irrigation of nearby agricultural land, water stored in the irrigation pond is used after it gets cooled by natural cooling through surface evaporation. There is a scope of examining the feasibility of steam operated absorption chillers in place of the steam jet refrigeration system, and solar heat can be an alternative to biomass. This system can also be utilized as a cold storage for vegetables and fruits, when there is no need for milk pasteurization.

This multi-generation system will run entirely on renewable energy resources available locally, i.e., waste biomass, which is carbon neutral, meeting the affordable and clean energy and climate action related Sustainable Development Goals. Installation of this system can help in generating more income for farmers. The payback period has been estimated to be less than six months. An additional income for farmers will help in achieving “No Poverty” goal is also met. It will fulfil the clean water and sanitation goals by supplying drinking water to school students. In addition, good health and overall wellbeing of rural people are also made possible through this system. Therefore looking at the multiple benefits of this integrated system, it can be concluded that this may be one of the steps toward achieving sustainable development goals through rural development by 2030.

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