

The Feasibility of a Proposed Plant Design of Sheep Wool Insulation Material in Jordan to Eliminate the Negative Environmental Impact of Wasted Sheep Wool

Khalid M. Al-Malah, Mais R. Al-Khalafat, Nataly A. Al-Zayadeen, Aseel S. Al Mfalfal, Bahieh M. Alma'atah, Taha M. Alkhamis*

Department of Chemical Engineering, Mutah University, Karak, Jordan
Email: *alkhamis@mutah.edu.jo

How to cite this paper: Al-Malah, K.M., Al-Khalafat, M.R., Al-Zayadeen, N.A., Al Mfalfal, A.S., Alma'atah, B.M. and Alkhamis, T.M. (2025) The Feasibility of a Proposed Plant Design of Sheep Wool Insulation Material in Jordan to Eliminate the Negative Environmental Impact of Wasted Sheep Wool. *Journal of Environmental Protection*, 16, 130-147.

<https://doi.org/10.4236/jep.2025.162007>

Received: January 15, 2025

Accepted: February 25, 2025

Published: February 28, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This applied research seeks to explore feasible plant design for manufacturing insulation materials for construction projects using waste sheep fleece to address environmental issues related to wasted sheep wool and enhance the gross national product. The process starts by collecting low-cost sheep fleece from farms and processed via a production line, including scouring, plucking, carding, thermal bonding, and packing. The design process involves determining an optimal location, infrastructure, staffing, machinery, environmental impact, and utilities. A final economic analysis is undertaken to estimate the product's cost, selling price, and break-even point based on the anticipated capital and operational costs. The plant is intended to process 6778 tons of sheep wool annually. The study suggests that Mafraq Industrial City is a perfect location for the plant, and purchasing land and structures is the optimal option. The projected capital cost is 1,416,679 USD, while the anticipated operational costs amount to 3,206,275 USD. Insulation material production is estimated to be 114,756 m³ annually. The material may be manufactured into 1 m wide, 0.05 m thick sheets for 2.02 USD per square meter. Thus, for a 10-year plant, a 2.47 USD/m² selling price breaks even in one year.

Keywords

Sheep Wool, Solid Waste, Plant Design, Insulation Materials, Jordan

1. Introduction

The three E's problems, namely energy, ecology, and economy, are some of the

most important issues affecting the entire universe. The primary hazard to the environmental structure is considered to be environmental pollution. Therefore, many international conferences and meetings are held to limit the intrusion of civil life and its complexities on the environmental future of the planet. However, it is not only industrial processes that enhance the threat of pollution, but processing of natural resources can have a great negative impact on the environment. Animal waste is one of the most important pollutants that pose a threat to the environment in developing countries. Animal dung is a major source of environmental pollution in third-world countries which is treated in many cases through production of biogas by anaerobic co-digestion processes [1]-[5]. Recently, the enhancement of biogas production rate has been the focus of many researchers [6]. Moreover, Process cost reduction through the utilization of solar energy as a heating source for bioreactors is one of the major research projects in biogas production from animal manure [7] [8]. Furthermore, economic feasibility improvement is another important area in processes of anaerobic biogas production enhancement [9]-[11].

Annually collected sheep wool represents another source of environmental pollution if it is not treated for feasible utilization. The random disposal of non-manufactured sheep wool is a source of environmental pollution in countries which do not have the means to produce useful wool products. Jordan is a country that annually produces about 4000 tons of sheep wool that must be disposed of as waste [12]. Besides the environmental pollution, health problems may occur to people due to dust particles associated with disposed wool as waste [13]. Moreover, the disposal of wool waste through direct incineration, which is one of the methods used by sheep farmers, is considered as a source of environmental pollution because of the gases emitted from this process. Furthermore, carbon dioxide and other potential gases such as nitrogen oxides can contribute to the pollution that causes climate change.

Previous studies showed different ways to benefit from sheep's wool based on the characteristics of the wool produced. One approach is represented by utilization of wool waste as a fertilizer through hydrolysis process. In addition to zinc, copper, and sulfur, a case study on Irish sheep fleece reveals that approximately 15% of the required nitrogen for Irish crops can be obtained from hydrolyzed sheep wool [14]. A review paper by S.S. Rahman *et al.* discusses the utilization of textile waste in construction and geotechnical industries [15]. Besides concrete reinforcement, thermal insulation material can be manufactured from textile wastes. Through an acrylic spinning process, recycled textile residue is shown to be a potential thermal insulation material [16]. Several research papers discuss the use of textile waste as thermal and acoustic insulation in construction projects [17].

Utilizing greasy wool into insulation building components is a challenge in the sustainable development framework and clean deal statement. Sustainable and innovative applications of animal waste could boost sheep farming and minimize environmental challenges [18]. Parlato *et al.* found that with computed sheep

wool, about 10×10^6 kg/year, more than 1.5 million soft mats or 11,5 million semi-rigid panels could be manufactured, equivalent to 6.5 million and 17 thousand square meters. Results from converting raw wool into new resources are the first step in establishing a new wool recycling process [18]. Aditya and colleagues (2017) reviewed 133 research publications on insulating materials for energy conservation in buildings. They acquired information about advancements in building thermal insulations and argued on doing a life-cycle study to reduce possible emissions by utilizing appropriate insulation materials [19]. They concluded that the most straightforward and efficient method for conserving energy is through building insulation technology. Cosentino *et al.* 2023 reviewed 84 research papers on natural bio-based insulating materials. They determined that in academic research, the environmental impacts related to physical attributes are more thoroughly investigated than embodied environmental impacts. Furthermore, the assessment of the physical properties of this material type typically emphasizes thermal conductivity. However, many studies fail to include other crucial factors of these materials, such as thermal capacity, lifespan, and environmental effects. They recommended conducting a thorough assessment of the qualities of various insulating materials, including both conventional and bio-based options [20].

Each year, Jordan produces a large amount of wool, which contributes to environmental pollution because not enough recycling practices are in place to reduce the negative impacts of these organic wastes [12]. Jordanian sheep's wool, however, is inappropriate for the textile industry due to its physical characteristics [12]. The only attempt to profit from sheep's wool was made on a personal level by a local charity organization, which consisted of gathering wool, stacking it in molds without processing, and selling it as a raw material to India at a low price. As a result, it is essential to provide alternative methods for producing a national good with financial benefits for individuals (farmers) and the nation, for use in construction projects, and to eliminate the negative environmental effects.

This study aims to assess the feasibility of introducing a thermal insulation material (TIM) for construction projects by exploiting Jordanian sheep fleece through technology transfer. A systematic plant design method is to be implemented to attain this objective. The environmental impact of the TIM industry will be investigated.

2. Methodology

The approach for assessing the feasibility of establishing a factory for the production of wool insulation materials for construction projects encompasses both technical and economical components. Material balance principles are employed to decide on the appropriate machinery, equipment, and water requirements for the project. The energy balance approach is employed to ascertain the optimal energy requirement. Conversely, economic feasibility encompasses the costs associated with raw materials, water, electricity, and taxes. Additionally, construction costs are evaluated in conjunction with transportation needs. The plant's location is

determined upon the aforementioned factors. Finally, a proposed product price is determined, and the payback period is calculated.

2.1. Proposed Project Steps

The proposed project begins with the selection of the product to be manufactured from sheep fleece (process selection), followed by the selection of the factory's location. Then, a flowchart depicting the information flow and machinery required to produce the final product is created. Following this, material and energy balances are performed to determine the size and specifications of the apparatus, as well as the required utilities and the appropriate plant scale. The layout of the facility is then determined based on the optimal distribution of equipment and auxiliary service divisions. In addition, the costs of various suggested alternatives are determined, and the optimum strategy of action is selected. In addition, a cash flow diagram is constructed from which the repayment period can be determined. The positive and negative environmental impacts of the project are evaluated and suggestions for future work and process modifications are made.

2.2. Plant Location

The decision on the location of the plant is crucial to the success of the project. Several factors are considered to decide on a location: Annual distribution of sheep, availability of land and facilities, availability of workforce, and potential market for the product. Annual distribution of sheep among Jordanian governorates is presented in **Figure 1**. Mafraq accounts for 31% of the overall sheep population. The combined contribution of the northern governorates, including Amman, Balqa, and others, along with Mafraq, amounts to 88% of the total population, while the southern governorates provide only 12%. This enhances the possibility of locating the plant in the northern part of the country.

The Hashemite Kingdom of Jordan has a total size of 89,342 km², and Mafraq is one of the twelve governorates of the country, and the second largest by area, after Ma'an Governorate. The Northern Badia region covers the majority of the whole area where all sheep farms are located. The governorate is located in Jordan's northeastern region, bordering Iraq to the east, Syria to the north, and Saudi Arabia to the south and east. It covers 26,552 km² and accounts for 29.6% of Jordan's total land area. It is located at (36.77) degrees east longitude and (30.23) north latitudes. **Figure 2** displays a schematic of the Jordan map illustrating the 12 governorates, including Mafraq, and their respective sizes. In terms of distances within Mafraq governorate, the longest distance is 288 kilometers from the Iraqi border to Mafraq industrial city; the distance to the Syrian border is approximately 23 kilometers; the distance to Irbid is approximately 58 kilometers; the distance to Amman is approximately 60 kilometers; and the farthest distance is 388 kilometers to Aqaba. These distances result in a competitive transportation cost if the facility is located in Mafraq industrial city, providing that the majority of the sheep population is in the north of the country.

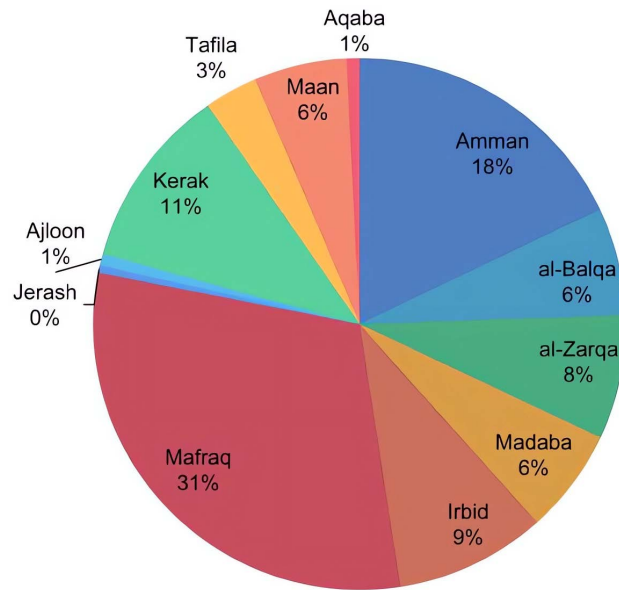


Figure 1. Distribution of sheep in Jordanian Governorates (adapted from Ref. 12).



Figure 2. Jordan map illustrating the 12 governorates including Mafrq (Adapted from [21]).

The above data makes it clear that the Mafraq Governorate makes up 31% of Jordan's yearly sheep production, making it a desirable location for the factory's proposed location. Every governorate, including Mafraq, featured industrial cities established by Jordan's Industrial Cities Company. All industrial cities have a comprehensive infrastructure that includes networks for electricity, communications, water, sewage, and rain drainage in addition to internal roadways. They also house all the authorities needed to provide rapid and easy services. The Jordanian government also reduces income tax to 5%, sales tax to 0%, customs duty to 0%, community service tax to 0%, and shares profit distribution tax to 0% for all industrial activities conducted in industrial cities. Some industrial cities, including the one in Mafraq, also provide subsidized rent or sales on the hangars required to establish production lines.

2.3. Workforce Availability

The unemployment rate in Jordan reached 22.8% in the first quarter of 2022. During that time period, men had a lower unemployment rate (20.5%) than women (31.5%) [22]. In 2021, the Civil Service Bureau received approximately 362,000 employment applications from people at the bachelor level for all professional specialties, compared to only 62,000 applications at the associate degree level [23]. This level of unemployment suggests that there is a sufficient workforce ready to carry-out the project. The largest Syrian refugee camp is located in Mafraq Governorate, which has a significant workforce potential.

2.4. National and Regional Market Availability

Jordan's population grew from over 5 million in 2000 to over 11 million in 2021, which increased demand for housing developments and necessitated the supply of heat and moisture insulating materials [23]. Consequently, there is a substantial local market for this product, and as the need for reconstruction in Syria and Iraq increases, it is probable that there will also be a demand for it there. If the product is technically and commercially viable, it may have a regional market in addition to a global market.

3. Process Identification

3.1. Process Information Flow-Sheeting

Figure 3 shows a suggested flow sheet for reproducing the procedure using specific equipment to complete the required task within the production line. The process starts with receiving wool from sheep farmers, storing it inside the plant prior to use, and then conveying it to the opening machine using an integrated conveyer. The opening machine, which is used to prepare wool for washing, initiates the process. So that the liquor can permeate more thoroughly, debris and dust must be able to escape from the fibrous mass, and the wool must be transferred to the scouring bowls in a more practical manner.

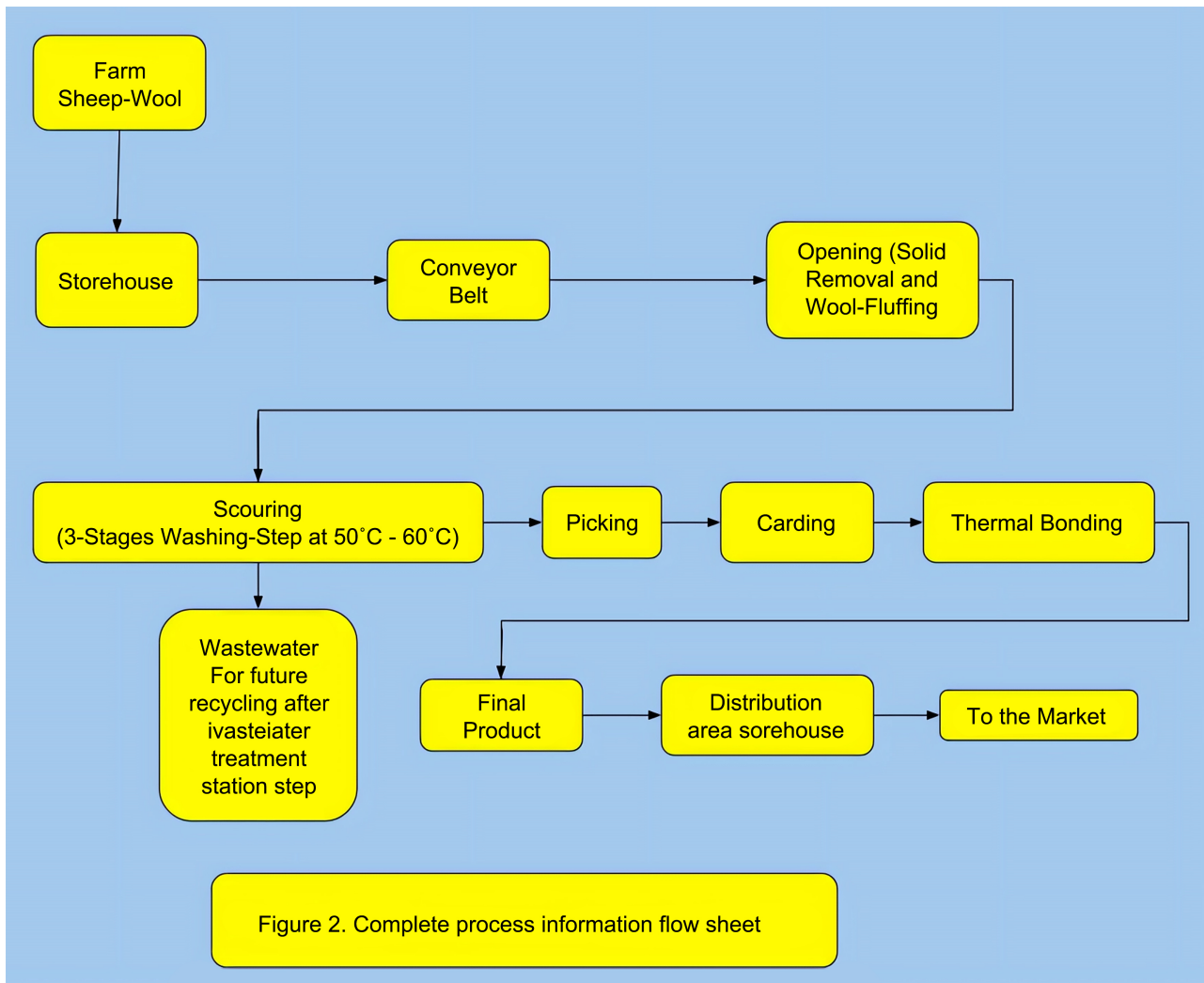


Figure 3. Qualitative sheep wool insulation material process flow sheet.

Machines that remove adhesive and dirt from fabric while simultaneously enhancing color penetration and dyeing are scouring and washing machines. The method increases the absorbency of the textile products by removing fats, oils, and waxy substances and adding other impurities with a certain amount of alkali. The contaminants, both natural and artificial, are thoroughly removed by three washing stages at 50°C - 60°C. Alkali is added to create a clean material, which is then left in a highly absorbent state without suffering any physical or chemical harm. This process also prepares the fabric for further processing.

A picking machine enters the process after the wool has been scourged but before it is carded; this machine performs the same job as the opening machine, which is to reduce impurities, with the exception that the wool in this instance has already been scourged. Using a succession of closely spaced, moving roller surfaces with pointed wire, pins, or teeth as covers, a carding machine separates the tangled clumps of fibers into a web of individual strands.

Thermal bonding techniques use heat energy to activate an adhesive system to

interlock fibers; bonding may be done separately, but it's typically done in conjunction with web formation. The finished product is then moved to the distribution area storage facility where it will be dispersed to a market using a carefully thought-out marketing strategy.

3.2. Data Acquisition, Equipment Sizing, and Energy Requirements

To conduct an economic feasibility assessment, data are gathered from a variety of sources that are pertinent to the various stages of the process. At each stage, material and energy balances are used to calculate the equipment sizing and energy needs for the operation. Jordan is anticipated to produce 3,585,962 sheep annually, or 6778 tons of wool, between 2017 and 2030 [12]. Therefore, the size of the equipment and the amount of energy required to process the annual production of wool are determined. The time of operation is divided into two shifts a day of eight hours each. Hence, the projected amount of wool that the plant would need to process would take 5840 hours of operation annually.

The necessary data that are required to calculate the optimal capital and operational production costs, which includes the two tracks for purchasing or renting hangars, the utilities, and the taxes, are acquired from the official Industrial Cities Company documentations. Moreover, labor cost is based on the declared minimum wage in Jordan market. Additionally, the payback period is determined using the optimal cost track and the market selling price of the product compared to the prices of the various types of well-known insulation materials.

4. Results

4.1. The Process

It is clear from the characterization of the sheep wool obtained from Jordanian Awassi that it can only be utilized as carpet and blanket material because its reported average fiber length is around 15 cm, and its reported average fiber diameter is about 34 μm [12]. The carpet and blanket industries, however, require sophisticated and expensive technologies to make goods that can compete in the local and global market. Therefore, it is important to investigate further applications for Jordanian Awassi sheep's wool. Utilizing this raw material's thermal qualities to create commodities that are urgently required in the local and regional markets is one tactic. Since the thermal conductivity of Awassi sheep wool is claimed to be at a level of approximately 0.033 W/m·K, which is comparable to that of polystyrene or rockwool, insulation materials appear to be the best candidate.

Sheep wool insulation material is also advantageous in that it is a low-cost insulation material product because the starting material (sheep wool) is less expensive than the starting materials required for other insulation materials, such as rockwool and polystyrene. Utilizing solid wastes from sheep fleece to produce insulation for construction projects is the optimal solution. As a result, a well-established technology of the necessary components for the proposed process has been selected as the basis for the construction of a plant to produce this material.

Figure 3 depicts a method for producing insulation from Awassi sheep fleece as a solid waste that was chosen as the basis for the proposed plant. Transferring sheep wool from storage to the opening unit, which serves to remove any foreign substances adhering to the wool, is the first stage in the process. This is followed by the fluffing step, which prepares the material for the next steps. Then, the material is moved to the scouring unit, where the wool is washed three times at 50–60 °C. At this phase, wastewater is collected and treated using an inside wastewater treatment unit prior to being recycled for the scouring process. This water effluent can be fully or partially employed to extract fatty acids for secondary by product, including cosmetics. This proposal will be examined in the future, ultimately reducing the plant's output costs.

The process needs drying the wool to a fine level of 16% - 17% percent by hot air flow, even though the last squeeze of the wool loses a substantial amount of water while retaining 50% (of the total weight) of the water.

The procedure then moves on to the picking unit where the dried wool is treated to eliminate any dust left over from the first two stages as well as to provide additional blowing and washing operations to prepare the material for the carding unit. At this point, the wool is being combed, a controlled process that transforms wool from coarse to fine. In the carding unit's final phase, the processed wool is arranged into thin sheets with all the fibers oriented in the same direction. This process is repeated until the appropriate thickness and width are obtained.

4.2. The Plant Location

According to **Figure 1**, Jordan's Mafraq Governorate has the most livestock, accounting for 31% of the total population. According to reference 12, Jordan will have an average of 35,585,962 sheep, so the Mafraq governorate would have an average of nearly 11 million sheep. In addition, it is estimated that an average of 6778 tons of sheep wool are produced annually, with Mafraq generating more than 2000 tons of that total. As was previously stated, the governorate of Mafraq generates the most sheep annually in Jordan. Within its industrial cities, land and infrastructure are readily accessible. In addition, the country has a labor market, particularly in Mafraq, which is adjacent to the largest camp of Syrian refugees. In addition, the area's proximity to highways leading to Aqaba, Syria, Iraq, Saudi Arabia, and the Arabian Gulf nations makes it a potential location for the regional and international sale of manufactured insulation material. Mafraq thus represents the optimal location for a plant manufacturing sheep wool insulation material.

Figure 4 shows an image of typical hangars at the King Hussein Bin Talal Development Area's Al Mafraq Industrial Estate, which opened in 2016. Al Mafraq Industrial Estate (Development Zone), 60 kilometers northeast of Amman, with a total area of around 1,847,000 square meters [24].

Figure 5 is a diagram of the proposed plant's layout, illustrating the administration buildings, production line housing, raw material and product storage buildings, and wastewater treatment unit. As stated previously, the building's area is 2599 square meters, while the proposed extension's land area is 1500 square meters.



Figure 4. A sample of a ready hangar available for leasing in the industrial area of Mafrag (Adapted from reference 24).

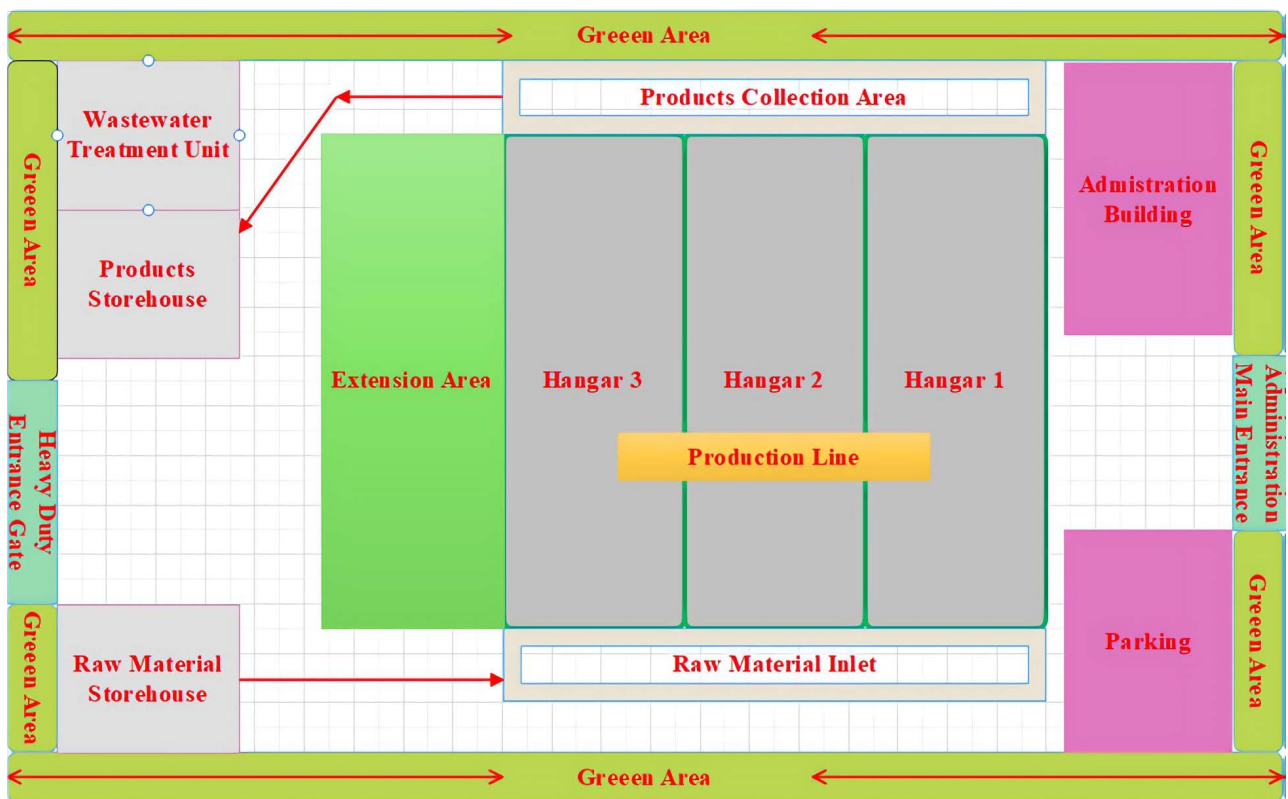


Figure 5. Suggested layout for the proposed sheep wool insulation material plant.

4.3. Estimated Capital Cost

Capital expenses for the proposed plant include the land, hangars, required machinery, and equipment. Within the industrial city of Mafrag, several purchase

and leasing alternatives have been researched, including those for purchasing land with existing hangars already there or purchasing the land and building your own hangars later. The other choices include renting the land and hangars entirely or in part. The entire renting option for a defined duration with the option to buy afterwards has been adopted most widely within the industrial city. However, it has been determined that purchasing land with hangars (buildings) is the best option for ensuring the success and stability of this particular project in terms of initial capital investment, assuming

the necessary funds are available. An average of 6778 tons of wool are expected to be produced annually between now and 2030. To house the equipment required for the production line, storage space, and office space, three hangars totaling 2599 square meters will be required: an additional 1500 square meters will be required for future expansion. Mafraq Industrial City (MIC) charges 25 JD per square meter for land without buildings and 175 JD per square meter for land with buildings. This is based on the current exchange rate of 1 JD to 1.41 US dollars. Alternatively, annual cost to lease land without or with buildings are 2.5 JD/m² and 20 JD/m², respectively [25] [26].

Based on the aforementioned information and the buy-and-rent choices offered by MIC, four possibilities are taken into consideration: the first is to buy the land with buildings; the second is to rent the property with structures; and the third is to buy the land and rent buildings. The fourth option stipulates that the purchase price three years after the initiation of the project is equal to the purchase price less 50% of the three-year rental value plus the first three-year rental value. Taking the fourth option into consideration, the three-year rent is 401,880 JD based on the required area and the required hangars. After three years, the cost to purchase the complex will be 492,000 JD, which, when combined with a 50% reduction in the rent value, results in a net value of 200,940 JD. This results in a total property cost of 692,940 JD over the life of the plant, which is significantly higher than the first option's total property cost of 492,000 JD.

Table 1 displays the estimated cost of land and structures (2599 m²) and expansion land (1500 m²) for the four available options. Comparing the total cost of the four options for the first ten years of the project, it is evident that option 1 is the optimal choice; consequently, all subsequent results are based on this option.

Table 2 depicts the prices of the main machines required to establish the production. Based on the prices of the year 2022, it is estimated that these main machines will cost a total of 233,261 JD (333,230 US \$).

The estimated number of personnel needed to operate the plant is 31, covering all departments. Using the average wage for every category of employee, the total annual cost would be 181,200 JD (255,574 USD). This cost is assumed to be a part of the equipment's capital cost if such wages do not change during the equipment's proposed 10-year lifespan.

Based on the results presented above, the estimated total capital cost for option one is 1,004,424 JD, or 1,416,679 US dollars. The capital cost included the cost of

the structure, the extension area, the main machines and assembly, and the necessary auxiliary equipment.

Table 1. A comparison of the four alternative scenarios in terms of the land and building costs necessary to launch the project.

Option No.	Option description	Total cost (JD)	Total cost for the first 10 years of the project (JD)	Total cost for the first 10 years of the project (US \$)
1.	Buying the land and the structures	492,000	492,000	693,935
2.	Renting the land and the structures	133,960 per year	1,339,600	1,974,048
3.	Buying the land and renting the structures	102,475 + (51,980 per year)	622,275	877,680
4.	Renting the land and structures in the first three years, then buying both with reduction on the price of 50% of the three years renting value.	692,940	692,940	977,348

Table 2. Main machines and auxiliary equipment cost (2022-year prices).

Machine function	Price (JD)	Price (US \$)
Scouring machine	138,255	195,000
Picking machine	7090	10,000
Carding machine	36,868	52,000
Thermal oven	51,048	72,000
Auxiliary equipment (pumps, Bar screen, Settling tank, Decanter discs, Heat exchangers, Jacketed vessel)	82,190	115,924
Cost of assembly (5% of the price of the machine)	15,773	22,246
Total Cost	331,224	467,170

4.4. Estimated Operational Cost

Raw materials, detergents, utilities, labor, and taxes comprise the operational expenses. To process the annual quantity of sheep wool produced, it has been determined that 10,400 kg must be processed each day during the proposed 16-hour workday. A daily expenditure of 5200 JD, equivalent to an annual cost of 1,898,000 JD (\$2,677,010 USD), is accrued when the price of raw sheep fleece, including transportation, is set at 0.5 JD, as farmers primarily seek to dispose of the gathered

sheep wool. It is estimated that cleaning this quantity of raw materials with detergents will cost 24,528 JD (34,595 US \$).

Material balance over the various units for water and wastewater yields a total annual cost of 227,468 JD (320,829) based on 1.3 JD per cubic meter for fresh water and 0.75 JD per cubic meter for treated wastewater. On the other hand, energy balance around the electric machines and the various electric auditing elements results in a total annual cost of electricity of 123,253 JD (173,841 US dollars), based on daytime rates of 0.068 JD/kWh and nighttime rates of 0.065 JD/kWh. This ultimately results in estimated annual operational costs of 2,273,249 JD (3,206,275 US \$).

4.5. Total Estimated Cost

The estimated total cost for the initial year of the project is 3,277,673 JD (\$4,622,955 USD). Starting the second year and throughout the plant's lifetime, the estimated annual cost is reduced to 2,454,449 JD (3,461,820 US dollars) because the price of land and structure is paid only once, assuming that the cost of electricity, water and wastewater treatment, and labor remains constant.

4.6. Estimation of Product Price

Based on the applied material balance equations, the net quantity of wool produced after washing operations and entering the thermal furnace is 393 kg/hour, leading to a total annual production of 2,295,120 kg for 16 hours per day and 5840 hours annually. If we assume that the density of wool generated is 20 kg/m³, then the annual production is 114,756 m³. The insulation material manufactured by the machine has a width of 1.5 m and a thickness of 0.05 m; thus, 1 m³ produces 13.5 m in length. Thereby, 1 m³ of wool yields 20 m² of insulation material, with an annual production of 2,295,120 m². That leads to the cost of insulation material per square meter to be 1.43 JD (2.02 USD) for the first year, and 1.07 JD (1.51 USD) for the remainder of the plant's lifetime. Therefore, the suggested a reasonable selling price per square meter ranges from 1.5 to 2 JD (2.12 - 2.82 US \$), with an average of 1.75 JD (2.47 US \$).

Table 3. Comparison of the estimated price to the prices of other local insulation materials.

Material	Thickness (cm)	Density (kg/m ³)	Thermal conductivity (W/m.K)	Price (JD/m ²)
Foam	4 - 6	35 - 48	0.032	5 - 7
Rockwool	6 - 7	40	0.034	2.5 - 3
Polystyrene	3	13 - 20	0.032	1.8
Polystyrene	5	13 - 20	0.032	3.25
Sheep wool	5	20	0.033	1.75

In the market for insulating materials, the data shown in **Table 3** demonstrate that the installation of sheep wool insulation that has been proposed is highly competitive compared to other options.

4.7. Cash Flow and Payback Period

In the first year prior to operation, a total estimated capital expense of 1,004,424 JD is paid out. Annual operating expenses of 2,454,449 JD are spent beginning in the first year of operation. The total estimated annual revenue is 5,020,575 JD. Thus, the estimated capital cost and first-year operational cost of 3,458,873 JD can be paid in the first year of operation, in addition to a profit of 1,561,879702 JD. The projected profit for the second year is 2,566,126 JD (3,619,360 USD). Therefore, the payback period is one year of operation if an appropriate marketing strategy is implemented.

Figure 6 depicts the cash flow over the plant's lifetime of ten years for both constant and variable operational costs. The profit for the constant operational cost exceeds 1.5 million JD (2.1 million US \$) in the first year of operation and 2.5 million JD (3.5 million US \$) annually thereafter for the remaining 10 years of the plant's life. Alternatively, when a 5% increase in operational costs is assumed, the profit decreases from approximately 2.5 million JD (3.5 million US dollars) in the second year of operation to less than 1.5 million JD (2.1 million US dollars) in the tenth year of operation. The projections are predicted on the assumption that the selling price remains constant, which will face any increase above 5% in operational costs.

The data also implies that the payback period for an effective marketing strategy is one year.

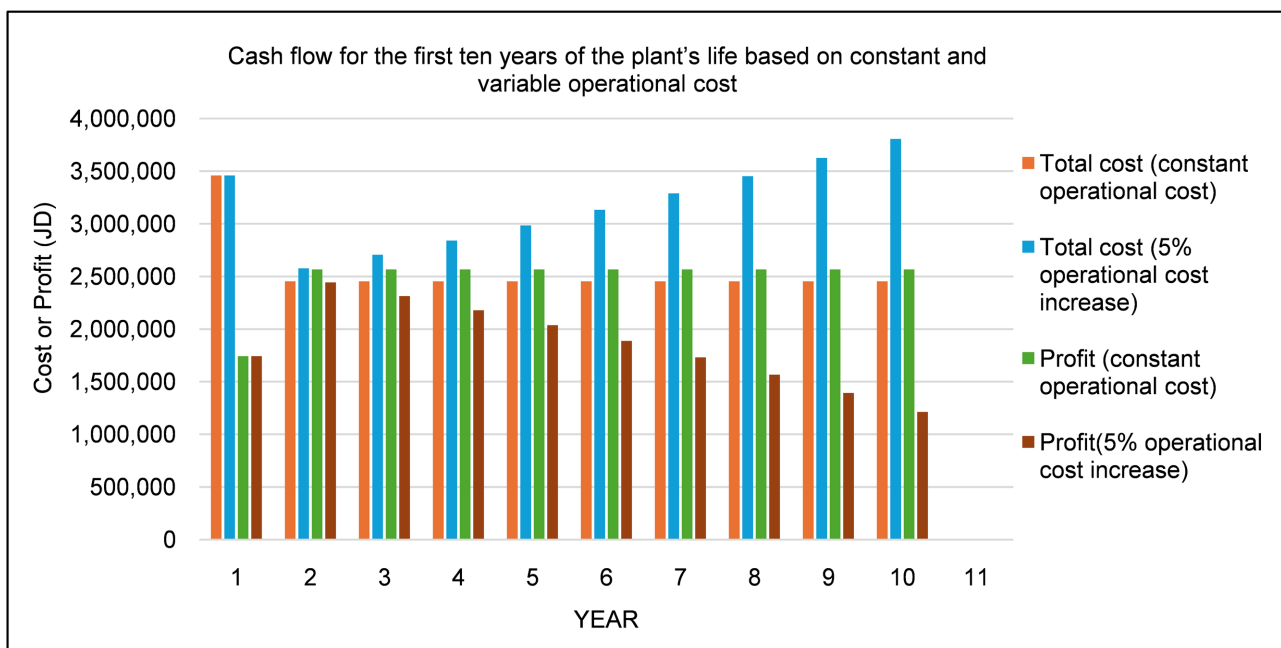


Figure 6. Cash flow for the first 10 years of the plant's life based on constant and variable operational cost.

5. Environmental Impact of the Project

The project does not have any detrimental negative influence on the plant's neighborhood. There will be no emissions, noise, or visual impact as the facility is situated in an established industrial city. On the other hand, establishment of the sheep wool insulation material plant will ultimately utilize all of the discarded wool that usually gets dumped into natural water sources or burned by cattle farmers. Providing a new source of income for livestock owners and sheep sector workers. It will also manufacture a local insulation product that can compete in price and quality with international products.

In addition, it will reduce the adverse effects caused by unpleasant odors and hazardous fumes resulting from the burning of wool, and it will create employment opportunities. On the other hand, the plant uses an excessive amount of water to clean the wool and get rid of the dust, dirt, and grease, which results in a considerable amounts of wastewater. Clay, lanolin, sheep manure, detergents, and the sheep's own discharge are just some of the organic toxic elements and microorganisms released during the washing of wool. Organic materials, however, have the potential to be useful if an innovative treatment strategy for the management of wastewater is implemented. This might result in the creation of products like cosmetics and associated materials.

6. Discussion

As the country's economy encounters more challenges, entrepreneurship with innovative ideas has the potential to significantly improve economic conditions through an appropriate profit, distinguished management, and access to local and international markets. Due to the urgent need for a locally produced, nationally competitive product, the product might also involve excellent facilities to reduce production costs as well as the ability to persuade foreign investors to provide economic contributions with straightforward guarantees. The payback period is estimated to be one year from the start of the project, which appears to be very efficient, and the product is ultimately very competitive with other types of insulation materials in terms of price and quality.

A standard plant design approach is followed to produce insulation material out of wasted sheep wool in Jordan. The project will manage the Jordanian sheep wool which cannot be used as fabric material. The plant location is determined based on several factors: the number of sheep, the transportation lines, the workforce, and the availability of utilities. Industrial cities provide incentives such as tax reductions and reduced costs for land and buildings, which can facilitate the establishment of an insulation materials industry targeting sheep wool. The proposed plant design project findings indicate that sheep's wool insulation has the potential to rival existing insulation options in the market. Sheep wool is a sustainable and natural resource that possesses inherent qualities that make it attractive as an insulating material. Furthermore, establishing a wool insulation industry might provide a new use for an inexpensive resource that is currently deemed

as waste in Jordan and in some other parts of the world. The above findings support a previous study by Corscadden *et al.* which suggests that sheep fleece has the potential to be transformed into a sustainable, natural, and renewable insulation material that may be targeted to local, regional, or specialized markets [27].

The aforementioned findings indicate that utilizing sustainable Jordanian sheep wool as an insulation material for construction could potentially serve as a solution for the current challenges linked to wool waste. Moreover, the environmental issues caused by sheep wool can be solved by establishing a construction insulation material sector that is capable of processing all the sheep wool generated. Furthermore, in terms of return on investment, this project has the potential to start an industrial revolution not only in the nearby vicinity but also in the region.

7. Conclusions and Recommendations

The establishment of a long-term economic feasibility study was demonstrated to be an enormously successful effort based on the profitability of the project and the total financial results. In the long run, it is an important factor that will be considered by the decision-maker. Using high-quality machinery from international markets is seen as an essential strategy for transferring technologies. Addressing the environmental issues related to sheep fleece waste in Jordan and other comparable situations globally, establishing a sheep wool insulating materials industry can be an economically viable solution. Furthermore, the issue of unemployment can be partially resolved. The large quantity of effluent that contains minerals and organic elements that can be recovered and used in a variety of different chemical industries contributes to the potential for starting a sheep wool insulation material plant. These materials and minerals can be utilized in a variety of different chemical processes.

Acknowledgments

The authors wish to thank Engineer Abdelrahman I. Al-Far and Engineer Aya Fadel Abu Zineh for fruitful discussion on the process and the production line machines.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Alma'atah, B.M., Alzoubi, A.I. and Alkhamis, T.M. (2021) Biogas Production from Sheep Manure by a Simulated Underground Burial System Heated with Cascade-Controlled Solar Water Heated System, as an Indicator of Biomass Potential Contribution to Power Mix in Jordan. *Journal of Environmental Protection*, **12**, 125-140. <https://doi.org/10.4236/jep.2021.122009>
- [2] Hessami, M., Christensen, S. and Gani, R. (1996) Anaerobic Digestion of Household Organic Waste to Produce Biogas. *Renewable Energy*, **9**, 954-957. [https://doi.org/10.1016/0960-1481\(96\)88438-2](https://doi.org/10.1016/0960-1481(96)88438-2)

- [3] Song, L., Deng, L.W., *et al.* (2010) Biogas Production Potential and Characteristics of Manure of Sheep, Duck, and Rabbit under Anaerobic Digestion. *Transactions of Chinese Society of Agricultural Engineering*, **26**, 277-282.
- [4] Cu, T.T.T., Nguyen, T.X., Triolo, J.M., Pedersen, L., Le, V.D., Le, P.D., *et al.* (2014) Biogas Production from Vietnamese Animal Manure, Plant Residues and Organic Waste: Influence of Biomass Composition on Methane Yield. *Asian-Australasian Journal of Animal Sciences*, **28**, 280-289. <https://doi.org/10.5713/ajas.14.0312>
- [5] Abu-Hamattah, Z.S.H., Al-Jufout, S., Abbasi, B. and Besieso, M.S. (2010) Biogas Energy: Unexplored Source of Energy in Jordan. *International Conference on Renewable Energies and Power Quality (ICREPQ'10)*, Granada, 23-25 March 2010, 9-14.
- [6] Li, Y., Chen, Y. and Wu, J. (2019) Enhancement of Methane Production in Anaerobic Digestion Process: A Review. *Applied Energy*, **240**, 120-137. <https://doi.org/10.1016/j.apenergy.2019.01.243>
- [7] Alkhamis, T.M., El-khazali, R., Kablan, M.M. and Alhusein, M.A. (2000) Heating of a Biogas Reactor Using a Solar Energy System with Temperature Control Unit. *Solar Energy*, **69**, 239-247. [https://doi.org/10.1016/s0038-092x\(00\)00068-2](https://doi.org/10.1016/s0038-092x(00)00068-2)
- [8] Darwesh, M.R. and Ghoname, M.S. (2021) Experimental Studies on the Contribution of Solar Energy as a Source for Heating Biogas Digestion Units. *Energy Reports*, **7**, 1657-1671. <https://doi.org/10.1016/j.egy.2021.03.014>
- [9] Zhao, B., Chen, J., Yu, H., Hu, Z., Yue, Z. and Li, J. (2017) Optimization of Microwave Pretreatment of Lignocellulosic Waste for Enhancing Methane Production: Hyacinth as an Example. *Frontiers of Environmental Science & Engineering*, **11**, 152-160. <https://doi.org/10.1007/s11783-017-0965-z>
- [10] Hinds, G.R., Mussoline, W., Casimir, L., Dick, G., Yeh, D.H. and Ergas, S.J. (2016) Enhanced Methane Yields in High-Solids Anaerobic Digestion through Inoculation with Pulp and Paper Mill Sludge. *Environmental Engineering Science*, **33**, 907-917. <https://doi.org/10.1089/ees.2016.0129>
- [11] Cano, R., Pérez-Elvira, S.I. and Fdz-Polanco, F. (2015) Energy Feasibility Study of Sludge Pretreatments: A Review. *Applied Energy*, **149**, 176-185. <https://doi.org/10.1016/j.apenergy.2015.03.132>
- [12] Alma'atah, B.M. and Alkhamis, T.M. (2020) Sustainability of Sheep Fleece Utilization in Jordan as an Insulation Material to Decrease Environmental Pollution, Increase Farmers' Income, and Create New Job Opportunities. *Journal of Environmental Protection*, **11**, 821-837. <https://doi.org/10.4236/jep.2020.1110051>
- [13] Mansour, E., Loxton, C., Elias, R.M. and Ormondroyd, G.A. (2014) Assessment of Health Implications Related to Processing and Use of Natural Wool Insulation Products. *Environment International*, **73**, 402-412. <https://doi.org/10.1016/j.envint.2014.08.004>
- [14] Gillespie, G.D., Dada, O. and McDonnell, K.P. (2021) The Potential for Hydrolysed Sheep Wool as a Sustainable Source of Fertiliser for Irish Agriculture. *Sustainability*, **14**, Article 365. <https://doi.org/10.3390/su14010365>
- [15] Rahman, S.S., Siddiqua, S. and Cherian, C. (2022) Sustainable Applications of Textile Waste Fiber in the Construction and Geotechnical Industries: A Retrospect. *Cleaner Engineering and Technology*, **6**, Article 100420. <https://doi.org/10.1016/j.clet.2022.100420>
- [16] Gounni, A., El Wazna, M., El Alami, M., El Bouari, A., Cherkaoui, O., Mabouk, M.T., *et al.* (2018) Thermal Performance Evaluation of Textile Waste as an Alternative Solution for Heat Transfer Reduction in Buildings. *Journal of Solar Energy Engineering*, **140**, Article 021004. <https://doi.org/10.1115/1.4038786>

- [17] Islam, S. and Bhat, G. (2019) Environmentally-Friendly Thermal and Acoustic Insulation Materials from Recycled Textiles. *Journal of Environmental Management*, **251**, Article 109536. <https://doi.org/10.1016/j.jenvman.2019.109536>
- [18] Parlato, M.C.M., Porto, S.M.C. and Valenti, F. (2022) Assessment of Sheep Wool Waste as New Resource for Green Building Elements. *Building and Environment*, **225**, Article 109596. <https://doi.org/10.1016/j.buildenv.2022.109596>
- [19] Aditya, L., Mahlia, T.M.I., Rismanchi, B., Ng, H.M., Hasan, M.H., Metselaar, H.S.C., *et al.* (2017) A Review on Insulation Materials for Energy Conservation in Buildings. *Renewable and Sustainable Energy Reviews*, **73**, 1352-1365. <https://doi.org/10.1016/j.rser.2017.02.034>
- [20] Cosentino, L., Fernandes, J. and Mateus, R. (2023) A Review of Natural Bio-Based Insulation Materials. *Energies*, **16**, Article 4676. <https://doi.org/10.3390/en16124676>
- [21] <https://books.openedition.org/ifpo/4852>
- [22] Department of Statistics—Jordan (2022) <https://dosweb.dos.gov.jo/>
- [23] Public Service and Administration Commission—Jordan (Arabic) (2024). <https://spac.gov.jo/Default/Ar>
- [24] Jordan Industrial Estates Company—Jordan (2022) <https://www.jiec.com/en>
- [25] Abu Zineh, A.F., Al-Far, A.H., Hamzeh Yasin Ghadi, H.Y. and Al-Dmour, G.A. (2021) Plant Design of Insulation Material from Nationally Produced Sheep Wool. Department of Chemical Engineering, Mutah University.
- [26] AL-Mfalfal, A.S., AL-Malah, K.M., AL-Khalafat, M.R. and ALZayadeen, N.A. (2022) Economic Feasibility and Environmental Impact Assessment of a Proposed Sheep Wool Plant Design in Al-Mafraq Governorate. Department of Chemical Engineering, Mutah University.
- [27] Corscadden, K.W., Biggs, J.N. and Stiles, D.K. (2014) Sheep's Wool Insulation: A Sustainable Alternative Use for a Renewable Resource? *Resources, Conservation and Recycling*, **86**, 9-15. <https://doi.org/10.1016/j.resconrec.2014.01.004>