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Research Article

Walnut Pruning Residues as a Renewable Energy Resource for Greenhouse Heating in the South-Central Region of Chihuahua, Mexico

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Keywords: Biomass; Pruning residues; Sustainable energy sources

Abstract

The objective of this research was to estimate the energy potential of walnut pruning residues (biomass) as a renewable resource for use in greenhouse heating systems in the south-central region of the state of Chihuahua. To achieve this, data were collected on the weight of fresh firewood generated per tree based on trunk diameter, considering three common pruning methods practiced in the area. Additionally, the percentage of weight loss during the biomass drying process was determined, and the regional area cultivated with walnut trees was documented. Based on this information, the potential energy availability and the feasibility of its use as a sustainable energy source for the agricultural sector under controlled climate conditions were calculated.

Introduction

The global energy matrix remains largely dominated by fossil fuels—oil, natural gas, and coal—which together account for approximately 80% of the world's energy supply, despite the growing contribution of renewables. This continued dependence poses several critical challenges: the progressive depletion of fossil reserves, the ecological impacts associated with their extraction and use, and the high volatility of international energy prices. In response, it is imperative to diversify the energy portfolio through the adoption of clean and renewable sources.

The protected agriculture sector, particularly greenhouse production, is characterized by intensive energy consumption, with heating representing one of the main operational costs during colder periods. In this context, residual biomass—especially that derived from agricultural pruning waste—emerges as a viable alternative energy source. In many cases, such residues are either burned in open fields or discarded, leading to avoidable pollutant emissions. Their controlled use in heating systems could significantly reduce the consumption of diesel or natural gas.

In the south-central region of the state of Chihuahua, walnut production generates substantial volumes of residual biomass. However, its energy potential had not yet been precisely quantified.

This study focuses on evaluating this potential through sampling of fresh wood weight by trunk diameter and pruning type, assessment of moisture loss during the drying process, analysis of the energy content of dried biomass, and estimation of the total area cultivated with walnut trees in the region. Additionally, the thermal availability of local hot springs was analyzed as a possible complementary energy source.

The technical and economic analysis conducted allowed for the estimation of potential thermal energy output, potential savings in operational costs compared to fossil fuels, and the associated benefits in terms of emissions reduction and environmental improvement. Preliminary results indicate that residual biomass, in combination with geothermal sources, represents a sustainable and economically competitive option for greenhouse heating.

In conclusion, the south-central region of Chihuahua possesses a non-conventional energy source—walnut pruning biomass—with the potential to support a transition toward a cleaner and more efficient agricultural model, thereby contributing to global sustainability goals and climate change mitigation efforts.

Materials and methods

This study was conducted in the south-central region of the state of Chihuahua, focusing specifically on the municipalities of Meoqui, Saucillo, Julimes, and Aldama.

Estimation of residual biomass from walnut pruning

The amount of biomass generated from walnut tree pruning was estimated on a per-hectare basis through non-random sampling in two representative orchards:

- **Plot 1 – Municipality of Meoqui (Federal Highway 45):** Sample trees were randomly selected. For each tree, the fresh weight of recently pruned branches was recorded in kilograms, along with the trunk diameter measured at 50 cm above ground level. In addition, 30 wood segments of various diameters were collected for controlled drying. This procedure allowed for the determination of weight loss due to dehydration, enabling the conversion from fresh biomass to dry biomass.

- **Plot 2 – El Maguey Ranch, Municipality of Saucillo (Delicias–Naica Highway):** A similar procedure was carried out to obtain comparative data and validate the representativeness of the estimates under similar environmental and management conditions.

Estimation of cultivated walnut area

To contextualize and extrapolate the biomass data obtained, official records from the Secretariat of Agriculture and Rural Development (SAGARPA) in the city of Delicias were consulted. This updated information on the cultivated area of walnut orchards in the south-central region of Chihuahua enabled the projection of residual biomass estimates at the regional level.

Biomass drying and calculation of energy yield

The collected wood samples were subjected to a controlled drying process to determine the ratio of fresh weight to dry weight. Subsequently, Nelson's energy value tables were applied to calculate the energy yield of the dry biomass, expressed in kilocalories per kilogram (kcal/kg). This facilitated the estimation of the caloric potential of pruning residues as an alternative energy source.

Results and discussion

As detailed in the methodology section, firewood samples were collected from three distinct walnut pruning methods: selective pruning of large branches, thinning of multiple branch tips, and mechanized pruning. The collected data are summarized in Table 1, which presents the estimated dry weight for each sampled tree.

This dry weight was obtained by multiplying the fresh biomass weight by the percentage of mass retention after the controlled drying process. Finally, the equivalent energy content contained in the dry biomass of each walnut tree was calculated by multiplying the dry wood weight by a specific energy value of 19.8 kJ/g, in accordance with the values reported by Nelson (2006).

A linear regression analysis was performed using trunk diameter and dry wood weight to derive an algebraic function capable of predicting the amount of dry firewood obtained from each walnut tree based on its trunk diameter, for each type of pruning (Figures 1-3).

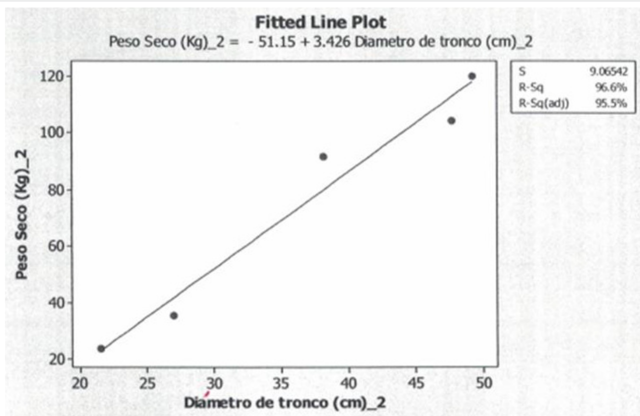

Figure 1: Selective thick branch pruning in "La 45" orchard (Cd. Meoqui). Pearson correlation coefficient between dry wood weight (kg) and trunk diameter (cm): 0.98.

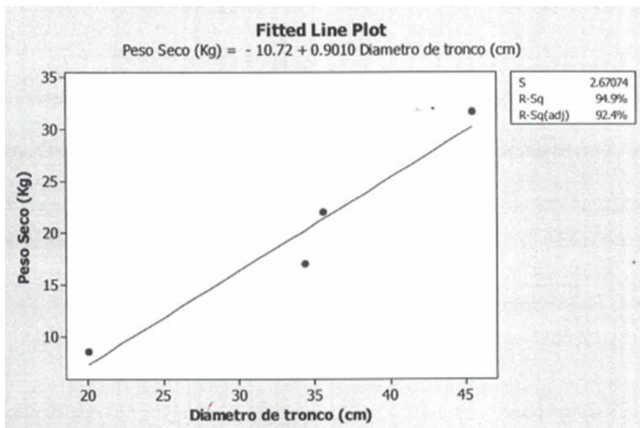

Figure 2: Multiple tip thinning pruning in "La 45" orchard (Cd. Meoqui). Pearson correlation coefficient between dry wood weight (kg) and trunk diameter (cm) = 0.9.

Table 1: Samples of Walnut Pruning Residues: 12 Trees and Three Pruning Types.

Tree No.	Pruning Type	Sampling Location	Trunk Diameter (cm)	Fresh Weight (kg)	Dry Weight (kg)	Equivalent Energy (kJ)
1	Mechanical pruning	El Maguey Orchard, Saucillo	28.64	26.8	17.1252	328,803.84
2	Mechanical pruning	El Maguey Orchard, Saucillo	43.60	77.2	49.3308	947,151.36
3	Mechanical pruning	El Maguey Orchard, Saucillo	40.74	61.3	39.1707	752,077.44
4	Selective thick-branch pruning	Las 45 Orchard, Meoqui	47.74	141.1	90.1629	1,731,127.68
5	Selective thick-branch pruning	Las 45 Orchard, Meoqui	27.04	47.8	30.5442	586,448.64
6	Selective thick-branch pruning	Las 45 Orchard, Meoqui	21.60	31.9	20.3841	391,374.72
7	Selective thick-branch pruning	Las 45 Orchard, Meoqui	38.18	123.7	79.0443	1,517,650.56
8	Selective thick-branch pruning	Las 45 Orchard, Meoqui	49.32	132.0	103.5180	1,987,545.60
9	Multiple-tip thinning	Las 45 Orchard, Meoqui	35.64	29.8	19.0422	365,610.24
10	Multiple-tip thinning	Las 45 Orchard, Meoqui	45.50	42.9	27.4131	526,331.52
11	Multiple-tip thinning	Las 45 Orchard, Meoqui	34.36	23.0	14.6970	282,182.40
12	Multiple-tip thinning	Las 45 Orchard, Meoqui	20.04	11.5	7.3485	141,091.20

Table 2: Summary of the Analysis of Pruned Branches.

Branch Number	Branch Diameter (CM)	Fresh Weight (KG)	Dry Weight (KG)	Equivalent Energy (KJ)
1	7.703	13.4	8.5626	164,401.92
2	12.57	47.7	30.4803	585,221.76
3	9.48	36.1	23.0679	442,903.68
4	6.65	9.0	5.755	110,419.20
5	7.73	14.2	9.0738	174,216.96
6	10.15	26.4	16.8696	323,896.32
7	5.82	7.2	4.6008	88,335.36
8	5.66	12.0	7.668	147,225.60
9	6.36	19.9	12.7161	244,149.12
10	7.51	11.5	7.3485	141,091.20
11	8.72	14.4	9.2016	176,670.72
12	10.56	38.7	24.7293	474,802.56
13	5.92	11.3	7.2207	138,637.44
14	8.78	24.8	15.8472	304,266.24
15	7.19	14.8	9.4572	181,578.24
16	12.09	47.5	30.3525	582,768.00
17	8.27	17.5	11.1825	214,704.00
18	9.48	26.8	17.1252	328,803.84
19	10.69	25.0	15.975	306,720.00
20	4.45	6.8	4.3452	83,427.84

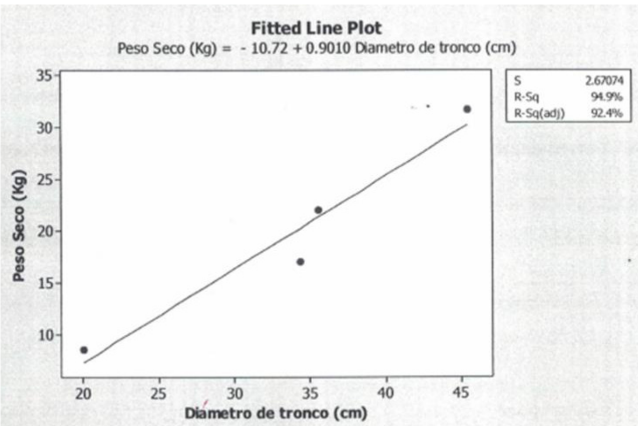

Figure 3: Machine pruning in El Maguey orchard (Cd. Saucillo). Pearson correlation coefficient between dry wood weight (kg) and trunk diameter (cm) = 0.991.

A correlation analysis was conducted between the trunk diameter of pruned branches and the volume of firewood generated under the selective pruning of thick branches modality. Table 2 presents the data corresponding to 20 analyzed branch samples. For each sample, the fresh weight of the firewood obtained from the recently pruned branches was recorded. Subsequently, the dry weight was calculated by multiplying the fresh weight by the mass retention percentage following the drying process (a detailed analysis of which is included in the corresponding section). Finally, the potential energy contained in the dry biomass was determined by multiplying the dry weight by an energy factor of 19.8 kJ/g, according to the values established by Nelson (2006).

Using the data, a linear regression analysis was conducted, resulting in three predictive functions to estimate the amount of fresh wood (kg), dry wood (kg), and equivalent energy (kJ) obtainable from a branch based on the branch's trunk diameter (Figures 4-6).

To quantify the weight loss experienced by fresh firewood during the drying process and thus more accurately convert fresh biomass values to dry biomass, samples of walnut tree trunks were collected. These samples were subjected to natural drying, remaining exposed to solar radiation from March 2009 to May 2010. Subsequently, an additional

Table 3: Analysis of Weight Change in Fresh and Dry Walnut Wood.

Trunk Number	Fresh Weight (kg) 05/03/2009	Semi-dry Weight (kg) 18/05/2009	Semi-dry Weight (kg) 20/04/2010	Dry Weight (kg) after 5 hr drying	Difference Fresh - Dry (kg)	Percentage Weight Loss (%)
1	0.045	0.03	0.02	0.02	0.025	55.56
2	0.045	0.03	0.02	0.018	0.027	60.00
3	0.26	0.185	0.186	0.186	0.074	28.46
4	0.84	0.61	0.594	0.584	0.256	30.48
5	0.77	0.56	0.564	0.552	0.218	28.31
6	1.65	1.235	1.19	1.176	0.474	28.73
7	3.4	2.555	2.344	2.322	1.078	31.71
8	0.05	0.04	0.04	0.038	0.012	24.00
9	0.06	0.045	0.044	0.042	0.018	30.00
10	0.63	0.44	0.43	0.424	0.206	32.70
11	0.125	0.08	0.082	0.078	0.047	37.60
12	0.705	0.495	4.66	0.454	0.251	35.60
13	0.355	0.23	2.28	0.224	0.131	36.90
14	0.015	0.01	0.01	0.01	0.005	33.33
15	0.015	0.01	0.012	0.01	0.005	33.33
16	0.1	0.065	0.66	0.064	0.036	36.00
17	0.055	0.035	0.032	0.032	0.023	41.82
18	0.06	0.04	0.038	0.038	0.022	36.67
19	0.095	0.06	0.064	0.064	0.031	32.63
20	0.19	0.12	0.12	0.116	0.074	38.95
21	0.18	0.11	0.112	0.112	0.068	37.78
22	0.305	0.16	0.164	0.16	0.145	47.54
23	0.26	0.165	0.166	0.162	0.098	37.69
24	0.305	0.19	0.196	0.192	0.113	37.05
25	0.055	0.035	0.034	0.034	0.021	38.18
26	0.605	0.395	0.382	0.378	0.227	37.52
27	0.185	0.115	0.12	0.116	0.069	37.30
28	1.095	0.75	0.728	0.718	0.377	34.43
29	0.055	0.04	0.044	0.04	0.015	27.27
30	0.13	0.075	0.082	0.084	0.046	35.38

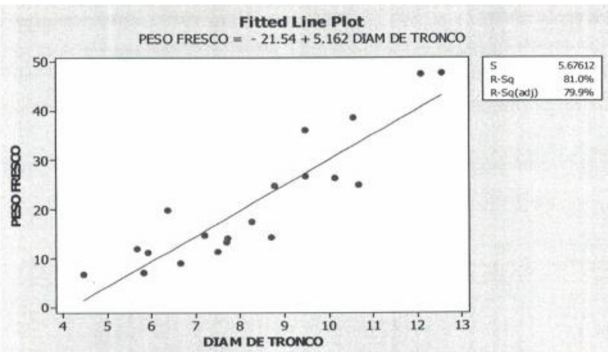

Figure 4: Linear regression graph of secondary branch diameter versus fresh weight.

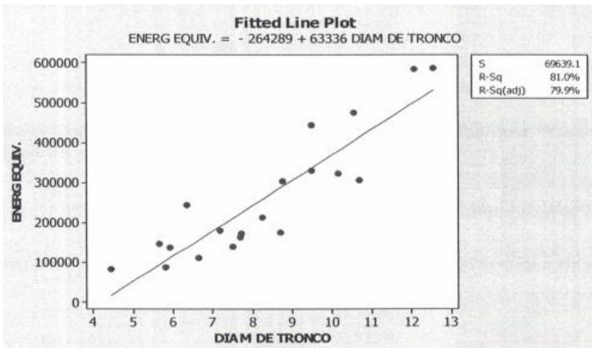

Figure 6: Linear regression graph of secondary branch diameter versus equivalent energy.

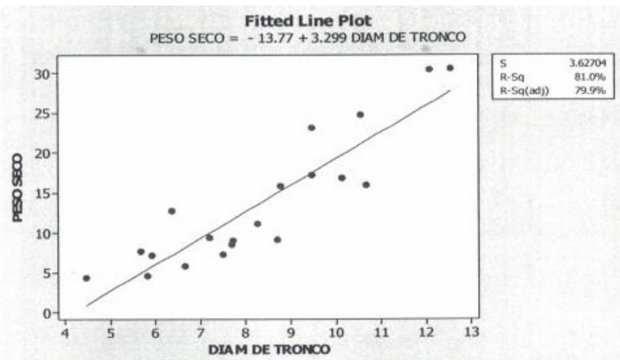

Figure 5: Linear regression graph of secondary branch diameter versus dry weight.

thermal treatment of six hours in an oven at 60 °C was applied. Based on these data, the arithmetic means of the mass loss recorded during drying were calculated, and their behavior is summarized in Table 3.

Additionally, information on the walnut cultivation area in the different municipalities of the central-southern region was compiled. This information allowed the estimation of the approximate amount of dry firewood generated by each type of pruning in each municipality. For this purpose, the developed linear regression functions (pages 22 and 23) were applied along with the arithmetic mean of the trunk diameter obtained from the analyzed sample. A planting density of 69 walnut trees per hectare was assumed, corresponding to a planting spacing of 12 x 12 meters.

The calorific potential was estimated by multiplying the dry firewood weight by the specific energy value of 19.8 kJ/g, according to Nelson (2006). Finally, this energy was converted to its equivalent in barrels of oil and its economic value in US dollars, considering a price of 82.5 USD per barrel, for each municipality evaluated in the central-southern region.

As an illustration, a calculation example is presented for the municipality of Camargo, with the following parameters: an arithmetic mean trunk diameter of 36.03 cm, a density of 69 walnut trees per hectare, and application of the function corresponding to selective pruning of thick branches (Figures 7-11) (Tables 4-6).

- Arithmetic mean trunk diameter = 36.03 cm
- Plantation density = 69 walnut trees/ha
- The selective pruning of thick branches functions: Dry weight = -51.15 + 3.426 × (Trunk diameter)
- Walnut cultivation area in Camargo = 5637.56 ha

Calculation: Dry weight = -51.15 + 3.426 × (36.03 cm) = 72.28 kg per walnut tree

This figure illustrates the estimated number of oil-equivalent barrels that could be obtained annually from pecan pruning residues using mechanical pruning methods across the South-Central region of Chihuahua. The calculation is based on the dry biomass energy potential and assumes an energy conversion factor of 19.8 kJ/g, with an economic valuation at a market price of $82.5 USD per barrel of oil.

Table 4: Recorded dry firewood amount and its equivalent energy calculated under the assumption of selective pruning of thick branches

Plantation Location	Area (ha)	Dry Firewood Weight (kg)	Equivalent Energy (TJ/year)	Equivalent Barrels of Oil/year	Cost (USD 82.5/barrel)
Camargo	5,637.56	28,116,315.74	556.70	97,529.48	8,046,181.74
S.F. de C.	991	4,942,434.12	97.86	17,144.25	1,414,400.22
Julimes	610	3,042,265.20	60.24	10,552.97	870,619.71
Meoqui	1,880	9,376,161.60	185.65	32,523.90	2,683,221.41
Rosales	1,680	8,378,697.60	165.90	29,063.91	2,397,772.32
Delicias	1,900	9,475,908.00	187.62	32,869.89	2,711,766.32
Saucillo	3,600	17,954,352.00	355.50	62,279.80	5,138,083.55
La Cruz	1,300	6,483,516.00	128.37	22,489.93	1,855,419.06
Total, Center-South región	17,598.56	87,769,650.26	1,737.84	304,454.11	25,117,464.32

The walnut orchard area data were provided by the Ministry of Agriculture and Rural Development (SADER).

Table 5: Record of the amount of dry firewood and its energy equivalent calculated under the assumption of multiple tip thinning pruning.

Plantation Location	Area (ha)	Dry Firewood Weight (kg)	Equivalent Energy (TJ/year)	Crude Oil Barrel Equivalent (barrels/year)	Equivalent Cost @ USD 82.5/barrel
Camargo	5,637.56	8,456,678.25	167.44	29,334.41	2,420,088.41
S.F. de C.	991	1,486,559.46	29.43	5,156.56	425,415.89
Julimes	610	915,036.60	18.12	3,174.07	261,860.44
Meoqui	1,880	2,820,112.80	55.84	9,782.37	807,045.29
Rosales	1,680	2,520,100.80	49.90	8,741.69	721,189.41
Delicias	1,900	2,850,114.00	56.43	9,886.43	815,630.88
Saucillo	3,600	5,400,216.00	106.92	18,732.19	1,545,405.87
La Cruz	1,300	1,950,078.00	38.61	6,764.40	558,063.23
Total – South Central Region	17,598.56	26,398,895.91	522.70	91,572.11	7,554,699.42

Table 6: Record of the amount of dry firewood and its energy equivalent calculated under the assumption of mechanical pruning.

Plantation Location	Area (ha)	Dry Firewood Weight (kg)	Energy Equivalent (TJ/year)	Barrels of Oil Equivalent/year	Cost (BOE) at $82.5 USD
Camargo	5,637.56	14,330,452.02	283.7429	49,709.27	$4,101,014.60
S.F. de C.	991	2,519,082.36	49.8778	8,738.16	$720,897.95
Julimes	610	1,550,595.60	30.7018	5,378.16	$443,741.42
Meoqui	1,880	4,778,884.80	94.6219	16,576.93	$1,367,596.52
Rosales	1,680	4,270,492.80	84.5558	14,813.42	$1,222,107.53
Delicias	1,900	4,829,724.00	95.6285	16,753.28	$1,382,145.42
Saucillo	3,600	9,151,056.00	181.1909	31,743.05	$2,618,801.85
La Cruz	1,300	3,304,548.00	65.4301	11,462.77	$945,678.45
Total Central-South Region	17,598.56	44,734,835.58	885.7497	155,175.56	$12,801,983.75

Source: Own elaboration. The data on pecan orchard surface area was provided by **SADER** (Secretaría de Agricultura y Desarrollo Rural).

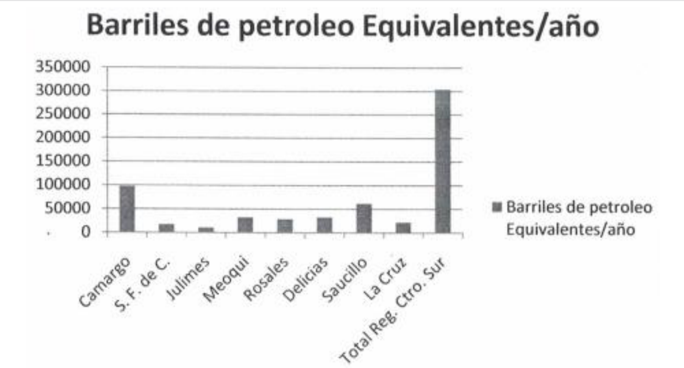

Figure 7: Walnut pruning wood equivalent in barrels of oil versus selective thick branch pruning scenario.

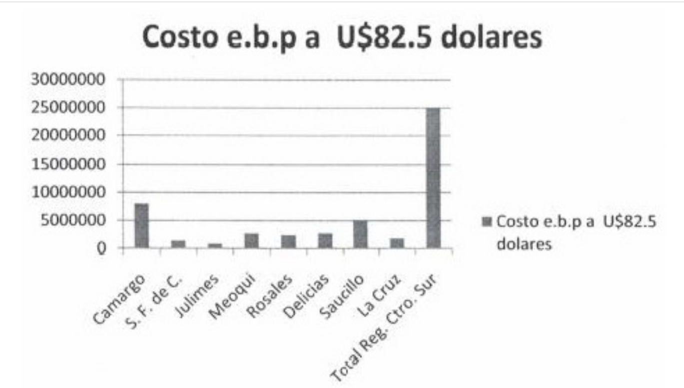

Figure 8: Equivalent cost in barrels of oil of walnut pruning wood, considering a price of 82.5 USD per barrel under the selective thick branch pruning scenario. Source: Own elaboration.

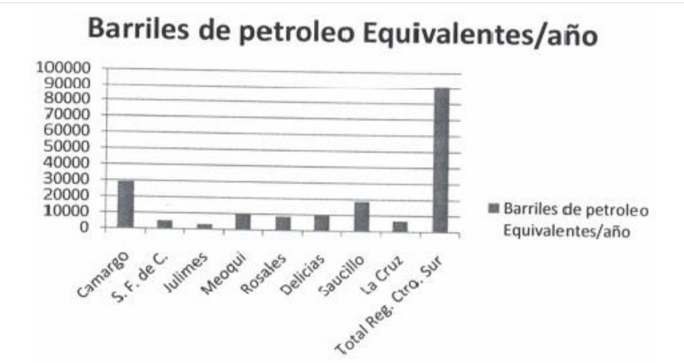

Figure 9: Equivalent of pecan pruning firewood in crude oil barrels under the assumption of multiple tip thinning pruning.

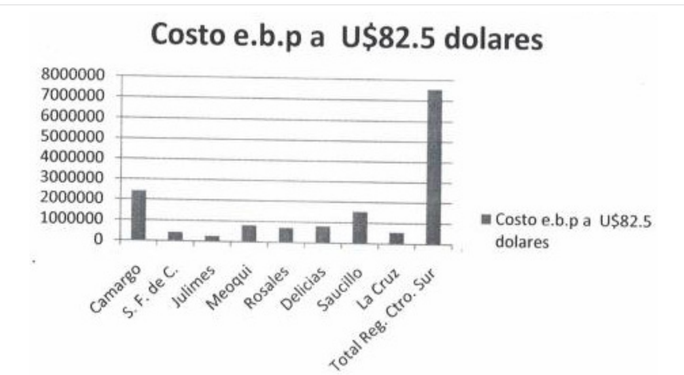

Figure 10: Equivalent cost of pecan pruning firewood in crude oil barrels under the assumption of multiple tip thinning pruning.

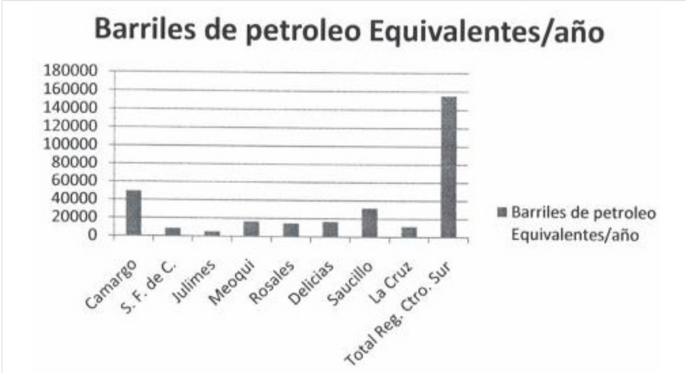

Figure 11: Pecan Pruning Wood Equivalent in Barrels of Oil under the Assumption of Mechanical.

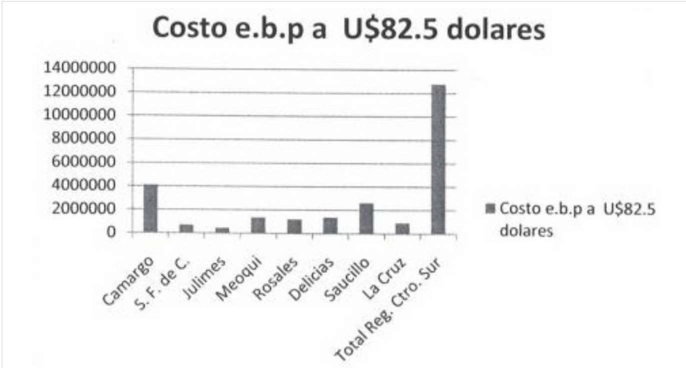

Figure 12: Equivalent Cost of Pecan Pruning Wood in Oil Barrels under the Mechanical Pruning Assumption.

This figure presents the economic valuation of dry pecan pruning biomass across municipalities in the South-Central region of Chihuahua, assuming mechanical pruning as the standard practice. The energy content was converted to oil barrel equivalents using an energy value of 19.8 kJ/g, and a reference oil price of $82.5 USD per barrel. The results highlight the potential financial savings associated with substituting fossil fuels with this renewable energy source.

Conclusion

Based on the analysis of the collected data, the following conclusions can be drawn:

- The potential production of pecan pruning wood in the south-central region of the state of Chihuahua could reach approximately 88,000 metric tons, assuming exclusively selective pruning of thick branches. Under the same assumptions, multiple-tip thinning would yield around 13,000 metric tons, while mechanized pruning could generate approximately 26,000 metric tons.

- The use of pecan wood as fuel in greenhouse heating systems would require the transportation of this biomass from orchards to greenhouse facilities. Additionally, pre-processing of the wood—such as cutting or conditioning—would be necessary to enable efficient feeding into burners, thereby generating local employment opportunities.

- A comparison of the energy value of pecan firewood to the market price of oil barrels indicates an estimated cost of $0.285 USD per kilogram of dry wood, suggesting a favorable margin for covering processing and handling expenses.
- The replacement of fossil fuels with pecan pruning biomass could represent significant savings, with an estimated reduction of approximately 300,000 barrels of oil per year when relying solely on selective pruning. In the case of multiple-tip thinning, the potential savings are around 100,000 barrels, and for mechanized pruning, about 155,000 barrels.

Recommendations

- It is recommended that greenhouse installations be strategically located to minimize the logistical costs associated with biomass transportation, thereby enhancing the overall economic viability of the heating system.
- It is advisable to develop and implement physical treatments for the biomass, such as shredding or chopping, to facilitate both transport and continuous, efficient feeding into combustion systems.
- Improvements in the combustion efficiency of pecan wood should be prioritized to maximize its energy potential in greenhouses. This is particularly relevant considering that open burning, a common practice in the region, results in low energy efficiency and contributes to increased environmental pollution.

Acknowledgment

We sincerely express our deepest gratitude to God, whose unwavering presence and trust have provided us with strength and confidence throughout the development of this project. Feeling His guidance has been essential in overcoming challenges and moving forward with hope toward the achievement of our objectives. We acknowledge that His divine direction has been a fundamental pillar at every stage of this research and will continue to support us in our future endeavors.

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