INDONESIAN JOURNAL OF INNOVATION AND APPLIED SCIENCES (IJIAS)
Journal Homepage: https://ojs.literacyinstitute.org/index.php/ijias
E-ISSN: 2775-4162

Volume 6	Issue 1	February (2026)	DOI: 10.47540/ijias.v6i1.2414	Page: 86 – 93

Potential of Cupressus *lusitanica* sawdust for pellet production using natural binding agents

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ARTICLE INFO

Keywords: Binding Agents, C. *lusitanica*, Pellets, Sawdust.

Received : 04 December 2025
Revised : 12 February 2026
Accepted : 24 February 2026

ABSTRACT

This study explored the potential of Cupressus *lusitanica* Sawdust for the production of pellets from carbonized sawdust using different natural binding agents (molasses, starch flour, fruit waste, and waste paper). The impacts of particle size and the type of binding agent used on the fuel qualities of pellets were investigated. The experimental results highlight that pellets produced from waste paper and starch flour binders exhibit high calorific values, high fixed carbon, and low moisture content. In contrast, molasses and fruit waste binders lower the fixed carbon and calorific value of pellets. As a result, the maximum calorific values were obtained using starch flour and waste paper, with respective values of 7052 and 7046 (cal/g). Maximum fixed carbon contents were 79.5% and 76.67% for waste paper and starch flour bonded pellets. Fruit waste and molasses binders result in lower calorific values, with respective values of 4831 cal/g and 5034 cal/g respectively. Pellets produced from fruit waste and waste paper showed lower ash contents of 1.53% and 1.67% respectively, indicating their environmental advantages. Therefore, starch flour, waste paper, molasses, and fruit waste are effective binders for biomass pellet production with improved quality.

INTRODUCTION

Petroleum-based fuels, including coal, oil, and natural gas, largely control the world's energy supply (IEA, 2022). Petroleum-based fuels account for over 81% the global energy supply (Ahmad & Zhang, 2020). Global climate change challenges and the exhaustion of fossil fuels have triggered the world to seek renewable energy alternatives (IEA, 2020).

Utilization of biomass for energy applications is an alternative approach to halting climate change, substantially substituting fossil fuels and lowering GHG emissions (Saleem, 2022). Biomass represents a promising potential energy source that is clean and sustainable (Regmi et al., 2021; Sher et al., 2020). In contrast to solar and wind power, biomass-derived energy provides a continuous and steady flow of energy that is not interrupted by climate change (Kabeyi & Olanrewaju, 2022).

Ethiopia has a huge potential for biomass that is not transformed into valuable products. Approximately 171,000 m^3 of woody biomass waste is produced annually (MEFCC, 2017). Woody biomass contributes more than 67% of the total energy supply in the country (Berhanu et al., 2017). Forest biomass is widely distributed and abundant in Ethiopia (MEFCC, 2018), and it is a substantial source for charcoal making (FAO, 2018) and firewood (MEFCC, 2017) production.

The wood residue is widely available in sawmill factories. The conversion of this wood residue into briquettes and pellets is economically viable and environmentally friendly (Pandey, 2022). The user- and environmentally friendly nature, applicability for a wider range of energy applications, and competitiveness in terms of production cost make biofuels the primary energy choice in Ethiopia (Tolessa, 2023).

Utilization of raw sawdust has several shortcomings, such as low calorific value, restricted bulk density, high level of moisture, and tendency to be wetted (Jaya, 2018). These inherent properties affect the effective utilization of sawdust and diminish its economic value (Benti et al., 2021), resulting in disposal in landfills. Densifying sawdust into pellets and briquettes boosts the bulk density to a high extent (Jaya, 2018), resulting in standardized physical attributes, consistent combustion behavior, enhanced energy content, increased density, and reduced moisture content. It also mitigates problems associated with handling, transportation, and storage (Akbar et al., 2021; World Bioenergy Statistics, 2019). Hence, woody biomass must be densified using economically feasible and environmentally friendly conversion technologies (Adams et al., 2018; Ullah et al., 2023).

Pellets are combustible solid biofuels produced from biomass feedstocks via a densification process (Cesprini et al., 2021). The market for biomass pellets has grown exponentially over the past ten years, indicating a new economic opportunity for society (Parajuli, 2021). Biomass pellets are made from any biomass material, such as forest residues, sawmill residue, straws, grasses, and energy crops (Pradhan et al., 2018). Sawmill industry residue and waste agricultural crops (Nabavi et al., 2020), soybean and cotton stalks (Abolee & S.R, 2022) are the most common materials used.

User friendliness, clean, high heat intensity, uniform size, and low bulk density are the common properties of pellets that make them more preferable over wood fuel (Kažimírová & Opáth, 2016). Moreover, pellets have superior burning efficiency compared to wood fuel. Pellets are a potential energy source to substitute fossil fuels in various heating applications (Flach & Bolla, 2022).

The parameters that affect the pellets' fuel qualities are:- the type of binding agent (Hu et al., 2015; Kpalo et al., 2020; Sermyagina et al., 2022), feedstock particle sizes (Harun & Afzal, 2016; Lisowski et al., 2020; Yılmaz et al., 2021), raw material moisture content (Huang et al., 2017), pretreatment method of feedstock (Shahrukh et al., 2016), and types of binders used (Kpalo et al., 2020). The deficiency in binding capability within lignocellulosic biomass gives rise to substandard pellets characterized by low strength, dustiness, and unsuitability for utilization. Consequently, several studies have explored ways to improve inter-particle binding efficiency within biomass pellets. The current study investigated how the type of binders used and the sieve sizes of sawdust affected the fuel qualities of pellets and the potential of *C. lusitanica* sawdust to synthesize pellets as an alternative energy source.

METHODS

Sample collection and preparation

Sawdust of *C. lusitanica* was collected from the Arsi Negelle wood process industry, located 167 km from Addis Ababa. The samples were dried in air to reduce the moisture content below 12wt.% and then sorted into 0.6 mm, 1.18 mm, and 2.36 mm sizes.

Carbonization of *C. Lusitanica* sawdust

Dried sawdust of *Cupressus lusitanica* was carbonized in an oxygen-deficient metal kiln for an average of 1 hour and 30 minutes. Carbonization enhances the energy value of materials (Niedziółka et al., 2015).

Pelletization process

A JS5RK/DL manual pellet press machine was used for the experiment. Molasses (Mol.), starch flour (SF), fruit waste (FW), and waste paper (WP) were used to bind the carbonized sample. During Pelletization, three kg of carbonized sample were mixed with one kg of binder. To facilitate the mixing process, a small amount of water was added. The mixture was densified into pellets and then dried in air to remove the remaining water.

Table 1. Characterization of Pellets

No	Test parameter	Standard method
1	Moisture content	ASTM D3173-11, 2017
2	Volatile matter	ASTM D3175-18, 2018
3	Ash content	ASTM D3174-12, 2018
4	Fixed carbon	ASTM D3172, 2015.
5	Calorific value	ASTM D5865-13, 2019
6	Durability	(ISO 17831-2, 2021).
7	Bulk density	ISO 17828, 2015

Data analysis

Data was analyzed using SAS software (Version 9). The experiment was conducted following a completely randomized design (CRD) with two factors: the binding agent and the particle size of the sawdust. Each treatment included three levels and three replications.

RESULTS AND DISCUSSION

Table 2. Physico-chemical properties of C. lustanica Sawdust (raw basis)

Elemental composition (Wt. %)				Fuel qualities (Wt. %)				
C	H	O	S	Moisture	Ash	Volatile matter	Fixed carbon	Calorific value (cal/g)
44.09	5.34	39.60	0.24	6.65	0.52	71.78	15.51	4587.96

Table 1 shows physicochemical properties and fuel qualities (ultimate and proximate properties) of raw Cupressus *lusitanica* sawdust. The Composition of C, H, O, and S affects the calorific value of the sawdust, and it is used to decide whether the selected species is good for energy production. A high carbon content indicates that the sawdust of C. *lusitanica* has good combustion properties. Furthermore, the sawdust has low ash and moisture contents. Therefore, a high percentage of carbon, low ash, and low level of moisture of *C. lusitanica* sawdust indicate its suitability for the production of good quality biofuels.

Table 3. Chemical Constituents of C. lusitanica Sawdust

Chemical composition	Unit (%)
Total extractive	3.26
Cellulose	46.45
Klason lignin	32.28

Table 3 shows the chemical composition of *C. lusitanica* sawdust in raw basis (without carbonization). The chemical composition of woody biomass has a significant effect on the mechanical properties of pellet fuels. Lignin in wood, which is used as a natural binder, has a high impact on the durability and strength of pellets (Yang et al., 2019). Woody biomass with high lignin content accounts for the production of more durable and harder pellets (Lulu et al., 2023). Lignin in *C. lusitanica* had a mean value of 32.28%.

Total extractives content varies from 3.25 to 3.5%, which is lower than that of other coniferous woods, which range from 5 to 8% as reported by Nisula (2018). According to the study by Faedo de Almeida et al. (2016), total extractives values of 3.87% was observed for C. *lustanica*, which is in agreement with the findings of the current research. Low extractive content result has a positive effect on the corresponding energy values of *C.lusitanica* (Shadangi et al., 2023). According to Kumar et al. (2020), high extractive content causes a significant decrease in heating value and fixed carbon of pellets.

Proximate and heating values of pellets synthesized using all the binding agents were significant at ($p < 0.01$). The effects of sieve sizes were significant at ($p<0.01$) as shown in Table.

Table 4. Analysis of Variance (ANOVA)

Variation source	Degree of freedom (DF)	Variance estimate				
		Moisture	Volatile matter	Fixed Carbon	Ash content	Calorific value
Particle size	2	0.0005Ns	0.067**	0.05**	0.133**	334195**
Type of binding agent	3	0.172**	0.052**	0.11**	0.40**	4169020**
Interaction effect	6	0.0024*	0.009**	0.012**	0.07**	1225586**
R^2		0.97	0.91	0.97	0.9	0.94

Particle size has shown a significant difference for volatile matter, fixed carbon, ash content, and calorific value. However, it has shown a non-significant difference for moisture content. The types of binding agents used have shown significant differences for moisture content, volatile matter, fixed carbon, ash content, and calorific value (Table 4).

Table 5. Interaction Effects of Particle Size and Binding Agents

Test properties	Sieve size (mm)	Types of binders			
		MOL	FW	WP	SF
Moisture content	0.6	9.7^{a}	5.75^{cd}	4.33^{f}	5.17^{f}
	1.18	9^{ab}	6^{c}	4.5^{f}	5^{f}
	2.36	8bc	6^{c}	4.67^{f}	5^{f}
Volatile matter	0.6	22.83^{ba}	18.9^{c}	14.83^{h}	15.5^{d}
	1.18	16.07^{d}	20.33^{b}	15^{e}	15.33^{e}
	2.36	25.33^{a}	23.4^{a}	18.83^{c}	19.83^{b}
Fixed carbon	0.6	60j	70.99^{f}	79.5a	75.17^{c}
	1.18	70.33^{g}	72.07^{d}	78.17^{ab}	76.67^{bc}
	2.36	63^{i}	69.07^{h}	71.17^{e}	70.33^{f}
Ash content	0.6	7.37^{a}	4.36^{d}	1.67^{e}	4.33d
	1.18	4.77^{b}	1.6^{f}	2.33^{e}	3^{e}
	2.36	3^{e}	1.53^{f}	1.75^{e}	4.5^{c}
Calorific value	0.6	6001^{f}	4831^{h}	6986^{abc}	7008^{abc}
	1.18	5034^{g}	6743^{d}	7046^{ab}	7052^{a}
	2.36	5801^{f}	5744^{f}	6566^{e}	6553^{e}

MOL- molasses; FW- fruit waste; WP- waste paper; SF- starch flour

Moisture level influences biomass ignition time and calorific value. It also affects the durability of compressed materials (Ungureanu et al., 2018). The results showed a highly significant difference and statistically uniform moisture values between sieve sizes and binding agents were observed in pellets produced using molasses binder with an average value of 8.9% (Table 5). The least and statistically similar moisture values were observed for wastepaper and starch flour binding agents with the values of (4.33%, 5.17%); (4.5%, 5%) and (4.67%, 5%) at respective sieve sizes (Table 5). The moisture obtained in the present study was below 10% with a mean value of around 7%. This agrees with the ASTM standard value, and it is considered optimal for combustion processes (Ungureanu et al., 2018). The moisture content result was in the range of 4.33% to 9.7%, and a similar finding was reported by Álvarez-Álvarez et al. (2018a). Molasses-bound pellets exhibited maximum moisture because molasses contains a high moisture level. Moreover, the moisture in molasses-bound pellets cannot be easily removed by drying due to the hygroscopic (water-absorbing) nature of molasses (Kotta et al., 2019).

Volatile matter

Minimum and statistically uniform volatile matter was obtained for starch flour-bonded pellets, with a value of 15.33% at the sieve size of 1.18 mm. For molasses-boded pellets, the maximum VM value of 25.33% was observed at 2.36 mm. Higher volatile matter for molasses-bonded pellets is due to high volatile organic compounds in molasses. Pellets produced using starch flour and waste paper showed minimum VM values of 15.33% and 15%, respectively, indicating lower concentrations of volatile organic compounds in the binders. Volatile matter affects the ignition and combustion stability of fuels. Higher VM facilitates easier ignition and produces more stable flames (Ozbayoglu, 2018).

Fixed carbon

Fixed carbon indicates the quantity of coke that will be obtained during carbonization (Maillot & Morau, 2023). FC is the main factor that determines the combustion properties of biomass pellets (Greinert et al., 2020). Wate-paper bound pellet exhibits the highest FC with a value of 79.5% at 0.6mm sieve size. These values are good compared to earlier experimental results reported by Amaya (2015), which found 61.6% and 73.6% pellet produced from molasses and starch binding agent. Whereas, the minimum percentage of FC 60% (0.6 mm) and 63% (2.36 mm) were recorded in pellets. Produced by using molasses binding agent (Table 5).

Ash content

Fruit waste and waste paper-bound pellets showed low ash percentage with respective values of 1.53% and 1.75% at a sieve size of 2.36 mm. These values are in agreement with previous findings of Sette Jr et al. (2016), where the reported values ranged from 0.3% to 3%. Molasses-bonded pellets showed a high ash content of 7.37% at 0.6 mm particle size.

Calorific value

Calorific value is a high heating value measurement that indicates the potential of fuels to propagate fires (Álvarez-Álvarez et al., 2018b). Binding agents and sieve size pellets have shown a highly significant difference, and similar results of calorific values were recorded for starch flour and wastepaper binding agents at a sieve size of 1.18 mm, with the respective values of 7052 cal/gm and 7046 cal/gm. The lowest CV (4831 cal/gm) was recorded for the fruit waste binder. It has been found that the pellets produced from starch flour and wastepaper binding agents at sieve sizes of 1.18 mm and 0.6 mm exhibit good fuel characteristics in comparison with pellets from fruit waste and molasses binding agents.

Dimension and bulk density

The pellets produced from *C. lustanica sawdust* were 28 mm long with a diameter of 8 mm. These values fall within the standard range for pellet dimensions—lengths of 3.15–40 mm and diameters of 6–8 mm. Pellets had a bulk density of 687 kg/m^3, which is in agreement with the ASTM standard range for pellet bulk density (600–750 kg/m^3). Similarly, this finding aligns the finding of Lee et al. (2020) which is 680 kg/m^3.

Durability of Pellets

The durability of C. *lustanica* pellets was greater than 97%. This result is consistent with the ASTM standard range of 96–97.5% (ISO 17831-2, 2021). Mechanically durable pellets can resist abrasion or shock without breakage during handling, storage, and transportation (Gilvari et al., 2020).

CONCLUSION

This study investigated the synthesis of biomass pellets through the densification of Cupressus *lustanica* sawdust to highlight the problems related to the traditional consumption of wood fuels. Pellets represent an alternative biofuel produced from various biomass feedstocks through the densification process. Locally available binding agents, starch flour, waste paper, waste fruit, and molasses, were employed to bind carbonized Cupressus *lustanica* sawdust. This study underscored the impacts of binders and sawdust sieve size on the physicochemical properties of pellets. The binding agents were mixed with carbonized sawdust at a three-to-one sample-to-binder ratio, with the addition of a small amount of water. The findings of the study revealed that waste paper-bound pellets displayed the highest fixed carbon content (79.5.02%) at 0.6 mm sieve size. High calorific values were obtained for pellets from starch flour and waste paper binders, with respective values of 7052 cal/g and 7046 cal/g, indicating their suitability for high-energy applications. On the other hand, fruit waste and waste paper-bound pellets exhibited lower ash content with respective values of 1.53% and 1.67%, reflecting superior environmental performance. Pellets from starch flour and waste paper showed high calorific values, fixed carbon, and low moisture content, indicating their high energy performance. The findings emphasize the potential of Cupressus *lustanica* sawdust as a promising biomass resource for pellet production and demonstrate the viability of agricultural and industrial by-products as sustainable binding agents for biomass pellet production, contributing to cleaner energy solutions, reduced environmental footprints, and the creation of job opportunities.

The current study did not examine the life cycle assessment of pellet production. Hence, future studies should focus on emissions analysis to evaluate the emissions profile of the pellets during combustion. Additionally, economic analyses should be carried out to determine the cost-benefit and a comparison of production costs of the pellets with conventional fuels, in addition to a scalability study to investigate the challenges and opportunities for scaling up the production for industrial applications.

CONFLICTS OF INTEREST

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

REFERENCES

Abolee, J., & S. R. K. (2022). Physio-chemical properties of pellets using different feedstock. *International Journal of Agricultural Sciences*, *18*(1), 18–23.

Adams, P., Bridgwater, T., Lea-Langton, A., Ross, A., & Watson, I. (2018). Biomass

Conversion Technologies. *Greenhouse Gases Balances of Bioenergy Systems* (107–139).

Ahmad, T., & Zhang, D. (2020). A critical review of comparative global historical energy consumption and future demand: The story told so far. *Energy Reports*, *6*, 1973–1991.

Akbar, A., Aslam, U., Asghar, A., & Aslam, Z. (2021). Effect of binding materials on physical and fuel characteristics of bagasse-based pellets. *Biomass and Bioenergy*, *150*, 106118.

Álvarez-Álvarez, P., Pizarro, C., Barrio-Anta, M., Cámara-Obregón, A., Bueno, J., Álvarez, A., Gutiérrez, I., & Burslem, D. (2018a). Evaluation of Tree Species for Biomass Energy Production in Northwest Spain. *Forests*, *9*(4), 160.

Álvarez-Álvarez, P., Pizarro, C., Barrio-Anta, M., Cámara-Obregón, A., Bueno, J., Álvarez, A., Gutiérrez, I., & Burslem, D. (2018b). Evaluation of Tree Species for Biomass Energy Production in Northwest Spain. *Forests*, *9*(4), 160.

Amaya, A. (2015). Preparation of Charcoal Pellets from Eucalyptus Wood with Different Binders. *Journal of Energy and Natural Resources*, *4*(2), 34.

ASTM D3172. (2015). *Standard method for fixed carbon determination of solid biofuel*.

ASTM D3173-11. (2017). *Standard Test Method for Moisture Analysis of Particulate Wood Fuels*.

ASTM D3174-12. (2018). *D1102-84 Standard Test Method for Ash in Wood*.

ASTM D3175-18. (2018). *Standard Test Method for Volatile Matter in the Analysis of Particulate Wood Fuels* (Vol. 18).

ASTM D5865-13. (2019). *ASTM E711—87 Gross Calorific Calorimeter*.

Benti, N. E., Gurmesa, G. S., Argaw, T., Aneseyee, A. B., Gunta, S., Kassahun, G. B., Aga, G. S., & Asfaw, A. A. (2021). The current status, challenges and prospects of using biomass energy in Ethiopia. *Biotechnology for Biofuels*, *14*(1), 209.

Berhanu, M., Jabasingh, S. A., & Kifle, Z. (2017). Expanding sustenance in Ethiopia based on renewable energy resources – A comprehensive review. *Renewable and Sustainable Energy Reviews.*

Cesprini, E., Greco, R., Causin, V., Urso, T., Cavalli, R., & Zanetti, M. (2021). Quality assessment of pellets and briquettes made from glued wood waste. *European Journal of Wood and Wood Products*, *79*(5), 1153–1162.

Faedo de Almeida, C. C., D'Angelo Rios, P., Bayestorff da Cunha, A., Melo Ampessan, C. G., & Spanhol, A. (2016). Applicability evaluation of Cupressus lusitanica for pulp production. *Maderas. Ciencia y Tecnología*, *ahead*, 0–0.

FAO. (2018). *Forest Products 2016 Year book, FAO Statistics, Rome.*

Flach, & Bolla. (2022). *EU Wood Pellet Annual*.

Gilvari, H., De Jong, W., & Schott, D. L. (2020). *The Effect of Biomass Pellet Length, Test Conditions and Torrefaction on Mechanical Durability Characteristics According to ISO Standard 17831-1*.

Greinert, A., Mrówczyńska, M., Grech, R., & Szefner, W. (2020). The Use of Plant Biomass Pellets for Energy Production by Combustion in Dedicated Furnaces. *Energies*, *13*(2), 463.

Harun, N. Y., & Afzal, M. T. (2016). Effect of Particle Size on Mechanical Properties of Pellets Made from Biomass Blends. *Procedia Engineering*, *148*, 93–99.

Hu, Q., Shao, J., Yang, H., Yao, D., Wang, X., & Chen, H. (2015). Effects of binders on the properties of bio-char pellets. *Applied Energy*, *157*, 508–516.

Huang, Y., Finell, M., Larsson, S., Wang, X., Zhang, J., Wei, R., & Liu, L. (2017). Biofuel pellets made at low moisture content – Influence of water in the binding mechanism of densified biomass. *Biomass and Bioenergy*, *98*, 8–14.

IEA. (2020). Key World Energy Statistics 2020. *Int. Energy Agency*, *33*(August), 4649.

IEA. (2022). *World Energy Outlook*.

ISO 17828. (2015). *'Determination of bulk density of solid biofuels*.

ISO 17831-2. (2021). *Determination of mechanical durability of soild biofuels*.

Jaya, S. T. (2018). Effect of pellet die diameter on density and durability of pellets made from high moisture woody and herbaceous biomass. *Carbon Resources Conversion*.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply. *Frontiers in Energy Research*, *9*.

Kažimírová, V., & Opáth, R. (2016). Biomass combustion emissions. *Research in Agricultural Engineering*, *62*(Special Issue), S61–S65.

Kotta, A. B., Patra, A., & Kumar, M. (2019). *Effect of molasses binder on the physical and mechanical properties of iron ore pellets", Effect of molasses binder on the physical and mechanical properties of iron ore pellets, 26*(1).

Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. (2020). Production and Characterization of Hybrid Briquettes from Corncobs and Oil Palm Trunk Bark under a Low-Pressure Densification Technique. *Sustainability*, *12*(6), 2468.

Kumar, Chandrashekar, Prasad, & Tailor. (2020). *Effect of extractive content on fuelwood characteristics of certain woody and non-woody biomass*.

Lee, J. S., Sokhansanj, S., & Lau, A. K. et., et al. (2020). Physical properties of wood pellets exposed to liquid water. *Biomass and Bioenergy*.

Lisowski, A., Matkowski, P., Dąbrowska, M., Piątek, M., Swietochowski, A., Klonowski, J., Mieszkalski, L., & Reshetiuk, V. (2020). Particle Size Distribution and Physicochemical Properties of Pellets Made of Straw, Hay, and Their Blends. *Waste and Biomass Valorization*, *11*(1), 63–75.

Lulu, Y., Eddy, I., Marsi, Novitri, H., & Hermansyah. (2023). The Chemical-Physical and Quality Parameters of Woods Pellets Generated from Revegetation Reclamation of Post-Coal Mining Land. *Journal of Ecological Engineering*.

Maillot, M., & Morau, D. (2023). Physico‐chemical characterization of Residual Household Waste for energy recovery in insular territories: Case study of Reunion Island. *Environmental Quality Management*, *33*(1), 107–119.

MEFCC. (2017). *Ethiopia's Institutional Framework for the MRV under the REDD+ Program*.

MEFCC. (2018). *Review of policies and strategies related to the clean cooking sector in Ethiopia final report, strengthening the enabling environment for clean cooking project*.

Nabavi, V., Azizi, M., Tarmian, A., & Ray, C. D. (2020). Feasibility study on the production and consumption of wood pellets in Iran to meet return-on-investment and greenhouse gas emissions targets. *Renewable Energy*, *151*, 1–20.

Niedziółka, A., Szpryngiel, M., Kachel, M., & Kraszkiewicz, A. et al. (2015). Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. *Renewable Energy*.

Nisula. (2018). *Wood Extractives in Conifers—A Study of Stemwood and Knots of Industrially Important Species*.

Ozbayoglu, G. (2018). Energy Production From Coal", in Comprehensive Energy Systems. *Elsevier*, 788–821.

Pandey, S. (2022). Wood waste utilization and associated product development from under-utilized low-quality wood and its prospects in Nepal. *SN Applied Sciences*, *4*(6), 168.

Parajuli, R. (2021). Wood pellets versus pulp and paper: Quantifying the impacts of wood pellets on the pulpwood markets in the southeastern United States. *Journal of Cleaner Production*, *317*, 128384.

Pradhan, P., Mahajani, S. M., & Arora, A. (2018). Production and utilization of fuel pellets from biomass: A review. *Fuel Processing Technology*, *181*, 215–232.

Regmi, S., Dahal, K. P., Sharma, G., Regmi, S., & Miya, M. S. (2021). Biomass and Carbon Stock in the Sal (Shorea robusta) Forest of Dang District Nepal. *Indonesian Journal of Social and Environmental Issues (IJSEI)*, *2*(3), 204–212.

Saleem, M. (2022). Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. *Heliyon*, *8*(2), e08905.

Sermyagina, E., Mendoza Martinez, C., Lahti, J., Nikku, M., Mänttäri, M., Kallioinen-

Mänttäri, M., & Vakkilainen, E. (2022). Characterization of pellets produced from extracted sawdust: Effect of cooling conditions and binder addition on composition, mechanical and thermochemical properties. *Biomass and Bioenergy*, *164*, 106562.

Sette Jr, C. R., Castro e Freitas, P. de, Freitas, V. P., Yamaji, F. M., & Almeida, R. de A. (2016). Production and characterization of bamboo pellets. *Bioscience Journal*, 922–930.

Shadangi, K. P., Sarangi, P. K., & Behera, A. K. (2023). Characterization techniques of biomass. *Bioenergy Engineering* (pp. 51–66).

Shahrukh, H., Oyedun, A. O., Kumar, A., Ghiasi, B., Kumar, L., & Sokhansanj, S. (2016). Techno-economic assessment of pellets produced from steam pretreated biomass feedstock. *Biomass and Bioenergy*, *87*, 131–143.

Sher, F., Iqbal, S. Z., Liu, H., Imran, M., & Snape, C. E. (2020). Thermal and kinetic analysis of diverse biomass fuels under different reaction environment: A way forward to renewable energy sources. *Energy Conversion and Management*, *203*, 112266.

Tolessa, A. (2023). Bioenergy Production Potential of Available Biomass Residue Resources in Ethiopia. *Journal of Renewable Energy*, *2023*, 1–12.

Ullah, S., Noor, R. S., Sanaullah, & Gang, T. (2023). Analysis of biofuel (briquette) production from forest biomass: A socioeconomic incentive towards deforestation. *Biomass Conversion and Biorefinery*, *13*(3), 1–15.

Ungureanu, N., Vladut, V., Voicu, G., Dinca, M.-N., & Zabava, B.-S. (2018, May 23). *Influence of biomass moisture content on pellet properties—Review*.

World Bioenergy Statistics. (2019). *A Technical Report on Global Bioenergy Statistics*.

Yang, I., Jeong, H., Lee, J. J., & Lee, S. M. (2019). Relationship between Lignin Content and the Durability of Wood Pellets Fabricated Using Larix kaempferi C. Sawdust. *Journal of the Korean Wood Science and Technology*, *47*(1), 110–123.

Yılmaz, H., Çanakcı, M., Topakcı, M., & Karayel, D. (2021). The effect of raw material moisture and particle size on agri-pellet production parameters and physical properties: A case study for greenhouse melon residues. *Biomass and Bioenergy*, *150*, 106125.