A Comparison Between Using Woody Biomass as a Heat Source or as Feedstock for Activated Carbon Production

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Agriculture generates a large volume of waste and contributes to environmental pollution. For instance, pruning the orchards leads to an abundant volume of woody residues. Disposing of this material improperly has adverse effects. Thus, it makes sense to convert this material into wood pellets or activated carbon (AC). This work compared these two options by producing samples of both types from the same biomass. A sample of AC was prepared in a fluidized bed reactor at an activation temperature of 580 °C and a residence time of 120 min. The life cycle assessment (LCA) technique was employed to assess the environmental impacts. Findings determined that the produced AC had a BET area and iodine number of up to 940 and 860 mg/g, respectively. Furthermore, the outputs of the LCA analysis demonstrated that wood pellets compared to AC had more environmental impacts for the global warming, abiotic depletion, ozone layer depletion, and photochemical oxidation indicators. Generally, the results showed that between the defined methods for managing the generated woody waste, using them as a feedstock for AC production is preferable to wood pellets production. In this case, the benefits for the farmers and the environment are significantly greater.

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INTRODUCTION

For millennia, humans have used wood to make fire to meet vital needs. This practice is still utilized in many countries. However, there are other valuable products that can be prepared from wood. Using this lignocellulosic biomass solely as a heat source is not always wise, especially when a country has to import those products. Nowadays, woody biomass is abundantly available in the world. It is mostly produced as a result of forestry and horticultural activities. Woody biomass can be used after its treatment by various practical processes, which convert it into either densified bio-based materials or directly into energy. Converting this waste into either materials and energy generally can be regarded as beneficial for humans and the environment. For instance, expanding utilization of the renewable energy sources has the potential to reduce or at least keep the fossil fuels consumption ratio at a fixed level.

The goal of the present work is to establish a comparison between two products that which can be derived from a woody biomass type that is available in Iran, which is one of the biggest oil producers in the world (Tofigh and Abedian 2016). The reasonable price of fossil fuels in this country has caused officials not to pay attention to replacing it with other energy sources. However the large production volume of woody waste in this country, and specifically in horticultural processes, has led to their conversion into wood pellets in order to later use them as a heat source. Using woody biomass as a heat source has certainly environmental burdens, and this is essential to evaluate these burdens accurately.

A combination of life cycle analysis (LCA) and techno-economic analysis (TEA) were used in this work to compare two alternative uses for prunings from an apple orchard. To this end, the biomass was converted either into wood pellets or into activated carbon (AC). Each product has various environmental impacts that need to be quantified, so as to find out which is more environmentally friendly. In addition, producing these residue-based products results in a revenue source. Therefore, it is logical to determine this income source's worth. To reach the above mentioned purposes, both economy analysis and environmental assessment should be implemented. The LCA method helps to reveal the environmental impacts relevant to a process in waste management or in a material or energy production cycle (Ekvall *et al.* 2007). Both the LCA and TEA approaches to managing woody residues are well aligned with the concept of a circular economy. In such a system, resources are kept in consumption cycle forever, and disposing of them in a landfill is avoided (Velenturf and Purnell 2021). Waste-based circular systems minimize the residues' detrimental effects on the environment, while maximizing any benefits obtained from them (Guman and Wegner-Kozlova 2020).

Because wood has been traditionally used to make heat, there have been many reports considering the consequences of its combustion for that purpose. Burning wood contributes to air pollution. The three most significant pollutants from burning firewood are potentially cancer-causing substances, which are called particulate matter (PM), soot, and black carbon (Ye *et al.* 2020). Additionally, carbon monoxide and nitrogen oxide are produced during the burning of wood (Vicente *et al*. 2020). When wood is used in cooking, it releases gasses and particles, which may have an effect on health and global warming (Gioda 2019). Stopping the use of firewood and substituting it with clean energy can minimize these detrimental effects. Nonetheless, the generated woody waste should be managed, and sometimes it is compelling to use burning as a solution. Generally, converting woody waste into value-added products such as AC instead of transferring this material towards firewood mills, can be much more beneficial for both the environment and human (Zhou and Wang 2020). In summary, considering a sharp increase in the woody waste production ratio makes it essential to evaluate them and then criticize the presented strategies to introduce the best attitude towards managing this kind of waste.

EXPERIMENTAL

Study Region

To have an integrated data set, a specific region was selected to study. This region is a small city in west Azerbaijan province of Iran, where agriculture is the primary occupation, and residents are mostly farmers. Approximately 7000 ha of farmlands are apple orchards and, annually, during the pruning season 9,000 tonnes of woody residue are generated. Farmers have not attempted to manage these residues, which has resulted either in their transfer to landfills or to their burning at the orchards. Table 1 includes the gathered data from the study region, this data set was extracted from the local organizations' databases. The farmers were surveyed to obtain complementary information.

Table 1. The Obtained Data

Item	Amount	Definition
Orchards area	7,500 ha	Apple orchards in the study region
Waste with diameter<40 mm	2,400 kg/ha	Has not any market Disposing by open burning or landfilling
The pruned orchards area	3,750 ha	3,750×2,400=9,000 tonnes/annum

Burning of wood emits gaseous pollutants and exacerbates air pollution. The calculations in Table 1 determined how much woody waste is annually generated in the study region. 9000 tonnes of woody biomass is a significant feedstock that can supply the needs of an industry; however, it can become an environmental catastrophe if it is not managed properly.

Production of AC

Another side of the comparison considers a valuable adsorbent that can be produced from lignocellulosic biomass. A sample of this substance was prepared in order to establish the comparison between it and the wood pellets. Therefore, 1 kg of AC was produced using a high-tech process. The used feedstock was the same as what was used in pellets production. A lab-scale fluidized bed reactor was employed to produce a sample of AC. A schematic of the configured reactor is illustrated in Fig. 1.

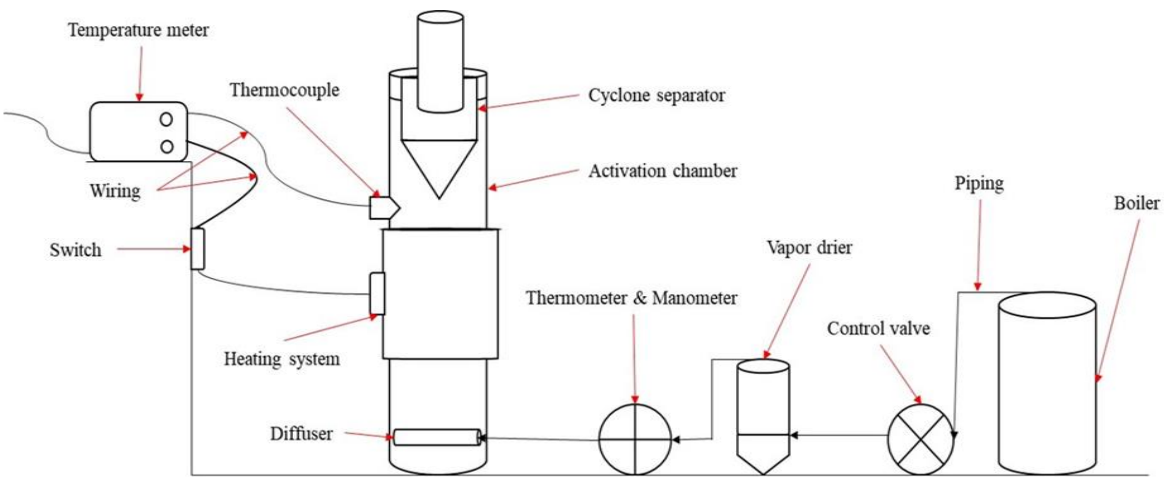

Fig. 1. The schematic of the configured lab-scale fluidized bed reactor

The activation agent was water vapor, and the activation temperature and residence time were 580 °C and 120 min, respectively. The produced AC was examined under standard tests. These tests were, namely: iodine number, particle size, moisture content, ash content, bulk density, hardness number, pH, and specific surface area (BET). These standard tests were carried out according to the corresponding ASTM and ISO standard organizations. Among the standard tests, BET is widely used to characterize porous structures (Ambroz *et al.* 2018). Determining its range was essential in this work, because valorizing AC depends on developing a higher surface area.

Valorization

The characteristics of AC and wood pellets were determined as a means of comparing their respective value. To this aim, a conversion ratio was also needed. Table 2 shows this ratio for woody biomass during AC production process. It should be considered that during the AC production, the woody residue was not entirely converted. This was because, in the course of the carbonization and activation processes, a significant amount of waste was lost as by-products such as ash. In comparison, the wood pellets production achieved a conversion ratio of 1:1. This means that in the pellet process, woody waste is converted into pellets with no loss.

Table 2. The Conversion Ratio During Converting Woody Biomass Into AC

Substance	Initial Amount (t)	Conversion Ratio	Product	Final Mass (t)
Woody biomass	9,000	5:1	Charcoal	1,800
Charcoal	1,800	1.2:1	AC	1,500

It was determined that in the carbonization stage with a high-temperature furnace, the conversion ratio was 5:1. This means that 1 kg of charcoal could be obtained from 5 kg woody biomass. Thus, the initial mass of material decreased markedly during transformation of the feedstock to the product. The same was true with respect to production of AC. Nevertheless, regarding the advanced production method (fluidized bed reactor), the conversion ratio in the activation stage was 1.2:1, and it caused the losses such as ash to decrease sharply. By disclosing the conversion ratio in AC and wood pellets production processes, further data such as total mass, worth, and emission were clarified relevant to these wood-based products. Collecting these specifications was essential for next evaluations.

Table 3 exhibits AC and wood pellets specifications and shows their worth. Regarding this schedule, the worth of 1 kilogram wood pellets against the same mass of AC was the main index for the next comparative investigations. To estimate the extracted AC's value, the market-based pricing technique was employed. In regard to this technique, a selling price was obtained by considering competitiveness between the same products in the market (Indounas 2019). An AC's value in the market is defined by considering its characteristics. This is also true in estimating wood pellets' value. These pellets selling price depends on their HHV range, and higher ranges result in higher worth.

Table 3. AC and Wood Pellets Valorization

Product	Specification	Range	Price (kg)
Wood pellets	High Heating Value (HHV) mj/kg	18.78	0.30 USD
AC	Purity (Quality) %	> 90	3.00 USD

For a comprehensive comparison, it was required to determine the differences between two products. Therefore, these wood-based products were evaluated based on the calculated data, and the extracted reliable selling price (worth). Table 4 summarizes the results of the calculations and shows total mass, worth, and emissions relevant to the products. In this table, to estimate the total emission of AC, the sum of emissions in both carbonization and activation stages were involved in the estimation process. In the carbonization stage, because of a low-oxygen environment, decomposition of woody waste releases emissions CO_2 eq. less than ordinary combustion. Therefore, turning 9000 tonnes of woody waste into charcoal was judged to be a cleaner process than wood pellets burning. However, the carbonized feedstock is a carbon product, and activating that by thermochemical process emits approximately 3.66 Kg CO_2 eq./kg. Hence, converting 1800 tonnes of carbonized charcoal into the AC ends up releasing a large volume of emissions.

Table 4. Total Mass, Worth, and Emission of Wood Pellets and AC

Item	Total Mass (t)	Total Worth (USD)	Kg CO_2 eq./kg		Total Emissions (t/annum)
Wood pellets	9,000	2,700,000	1.7 (Oguntoke *et al*. 2013)		≈15,000
AC	1,500	4,500,000	Carbonization stage	Activation stage	≈14,700
			0.9 (Vilén *et al.* 2022)	3.66 (Green 2008)	

Comparison

The previous steps provided the required information for establishing the comparison process. This process can obviously demonstrate what the outputs are. The final step reveals how much income can be earned if woody waste were converted into AC or wood pellets. To make the findings more understandable, they are shown in graphs. Ultimately, the extracted data from previous steps were analyzed in a comparative graph, which demonstrates the organized data in Table 4.

LCA

The LCA technique was employed to evaluate the effectiveness of each product relative to four environmental indicators. These indicators were global warming potential (GWP), abiotic depletion potential (ADP), ozone layer depletion potential (ODP), and photochemical oxidation potential (POP). Any indicator shows the potential of its occurrence; in other words, LCA can determine how much the environment is affected by converting woody biomass into wood pellets or AC and then consuming them. SimaPro software with the CML 2 baseline 2000 method was applied. This software has been described as a pioneering development in the field of environmental and social impact assessment (Oele and Dolfing 2019). CML methods represent 11 midpoint indicators (Raluy *et al.* 2005), which includes the evaluated ones in our research. This assessment's outputs were reported in individual charts.

To summarize this part of the work, first, the study region was assessed; then, data were gathered and normalized; after that, the produced adsorbent and wood pellets were evaluated; and finally, the two competing products were compared.

RESULTS AND DISCUSSION

The specific surface area can be used as an indication of relative quality of different activated carbon products. In the present work, carbonized feedstock was activated using a fluidization process to produce a high-quality AC. Because, this process assists to have proportional bed during activation stage, and leads to extract more porous AC (Wu *et al.* 2018). The outputs of the performed standard tests demonstrated notable facts, which proved an excellent AC. By the way of illustration, the specific surface area was 940 m^2/g. This is a desirable characteristic for a competitive AC, indicating that it is suitable to compete with similar products in the market. Generally, ACs with more than 900 m^2/g specific surface area are known as high capacity adsorbents. However, there are ACs with extremely high specific surface area, which have BET much more than 1000 m^2/g (Li *et al.* 2023). Table 5 shows specific surface area for some ACs produced from different biomass materials with various methods.

Table 5. Specific Surface Area of ACs Obtained from Some Biomass Materials with Different Methods

Feedstock	Method	Specific Surface Area	Reference
Palm kernel shell	Chemical activation	217 m^2/g	(Abechi *et al.* 2013)
Bamboo	Steam activation	719 m^2/g	(Mahanim *et al.* 2011)
Sugarcane bagasse	CO_2 activation	900 m^2/g	(Gonçalves *et al.* 2016)
Green coconut shell	Chemical activation	995 m^2/g	(Dipa *et al.* 2015)
Rice husk, corncob and wheat straw	Chemical activation using NaCl	281.7, 282.1, 290.2 m^2/g	(Ratan *et al.* 2018)
Tea woody stem	Chemical activation	789 m^2/g	(Tabak *et al.* 2019)
Orchard pruning	Steam activation	940 m^2/g	This work

Based on Table 5, it is apparent that apple pruning residue is a conducive feedstock to produce a porous adsorbent. In this table, among the feedstocks used for producing AC, only green coconut shell was reported to yield higher BET (995 m^2/g) than the biomass that was used in the present work to obtain AC. Coconut shell is a plentiful precursor for AC production. Nonetheless, it is not available everywhere. In some countries it is an imported good, which can increase the resulting AC's selling price. Thus, AC from woody biomass can be regarded as a low-cost adsorbent (Danish and Ahmad 2018). There are numerous precursors, which have been employed to convert biomass into AC.

Table 6 shows results of the performed standard tests for the produced AC characteristics. These indices make the product competitive with other similar adsorbents. The profitability of the process that was used to make the AC was evaluated. An excellent AC should have a high surface area and iodine number, but it should have a low moisture and ash content. Lignin and lignocellulose can be regarded as good precursors to produce ACs with a high specific surface area (Byamba-Ochir *et al.* 2016). In many applications, for instance, in wastewater treatment it is required that the specific surface area of the employed AC should be in the range of 900 to 1100 m^2/g (Azam *et al.* 2022). ACs from biomass are cost-effective compared to other sources such as coal; therefore, this fundamental attribute is helpful when introducing those to users. Agricultural waste (Mohan *et al.* 2008), for example; various trees, leaves, plant roots, fruit peels, and grasses are suitable precursors in ACs production (Gan 2021). Generally speaking, the findings determined that horticultural woody waste is a great precursor to turn into a valuable material. By doing this, it is possible to decrease pollution ratio, and improve productivity. Figure 2 compares production and emissions results for the two products.

Table 6. Results of the Standard Tests

Standard Test	Definition	Unit	Result
ASTM D4607	Iodine Number	mg/g	860
ASTM D2862	Particle Size	(mesh) mm	(10-12) 2-1.68
ASTM D2867	Moisture Content	% by Wt.	Max 5.5
ASTM D2866	Ash Content	% by Wt.	Max 1.1
ASTM D2854	Bulk Density	kg/m^3	430
ASTM D3802	Hardness Number	%	Min 82
ASTM D3838	pH	-	8
ISO 9277	Specific Surface Area (BET)	m^2/g	940

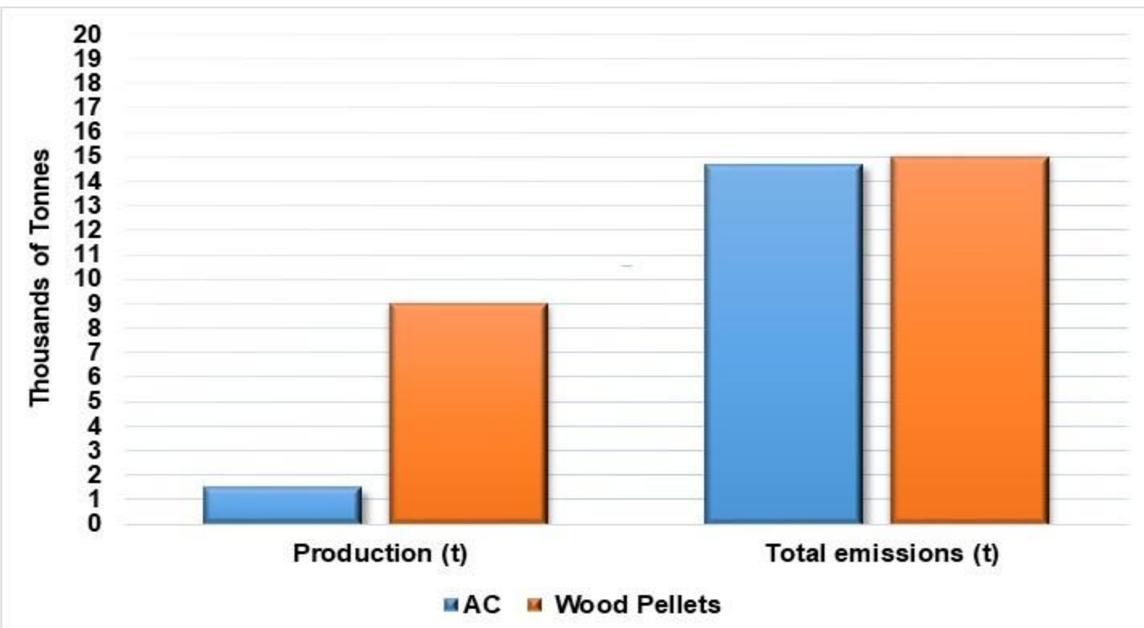

Fig. 2. The comparision between products

At a glance, it is obvious that sum of emissions in wood pellets consumption cycle is a bit higher than for the AC production process. This negligible difference in emissions is a result of the AC production process, particularly the carbonization stage. Because pyrolysis is a combustion in a low-oxygen ambient and the emitted gaseous emissions in this process are lower compared to ordinary combustion (Schwartz *et al.* 2020). However, in the activation stage, due to a high-temperature reaction and a pure carbon (carbonized feedstock), emissions' intensity is significantly higher. As an example, in 2012, an estimated 15.1 million tonnes of wood pellets were consumed in EU27 countries (Thomson and Liddell 2015). However, its environmental burdens must be assessed correctly, as it is seen, using this kind of heat source for domestic heating has adverse impacts on the environment. Conversely, converting the produced woody waste into AC can reduce the emissions, and brings an income source for the local farmers. In this comparison, it is shown that the total amount of emissions by using wood pellets for heating purposes is approximately 15000 t/annum, whilst it is 14700 t/annum for the AC production process. This is the biggest disadvantage of both products; nevertheless, to realize their impact on the environment, it should be referred to the outputs of the LCA analysis. Despite being cleaner than fossil fuels, wood pellets generate greenhouse gases significantly (Buchholz *et al.* 2017). In addition, total mass of production is another notable difference between the two products derived from the same woody waste. This mass was around 1500 t/annum for AC, while it was 9000 t/annum for wood pellets. As is well known, large production volume of a product leads to face with challenges; for instance, transportation. This issue is one of the important challenges in wood pellets production and supply chain (Magelli *et al.* 2009). Another fundamental difference between the products, is the benefits with converting woody waste into AC, which are considerably more than producing wood pellets from this waste. Figure 3 shows this discrepancy in the total predicted worth.

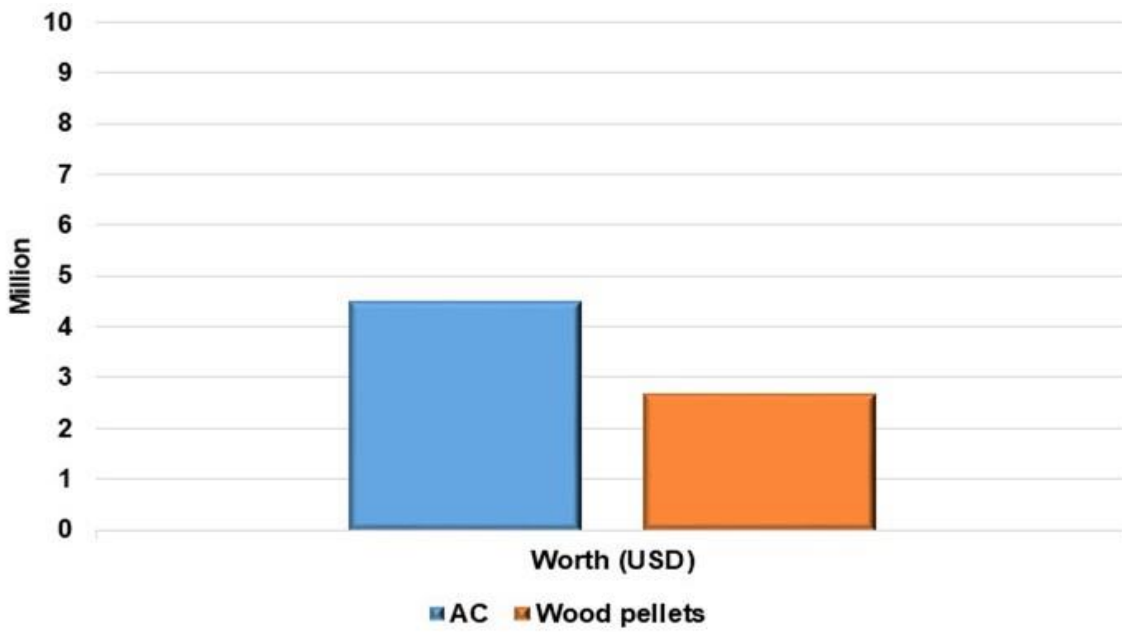

Fig. 3. The predicted worth of each product

The analyzed data revealed that total worth of the AC obtained from agricultural woody residues in the study region was 4,500,000 USD, where the corresponding values was 2,700,000 USD for wood pellets. Therefore, converting horticultural woody waste into AC instead of wood pellets, gives more benefits to the local farmers, particularly when they establish a waste-based local circular economy. Moreover, as mentioned before, the primary purpose of carrying out this research was to find a way to advantageously manage the generated residues, thus helping to conserve the environment. Conventional strategies for managing this waste just convert them into another form (wood pellets) that is intended for eventual combustion; thus, emissions are still produced. Utilizing pellets to make heat, reduces GHG emissions by around 78% compared to the coal, but NO_x and SO_x emissions are unfortunately still significant (Zhang *et al.* 2010). Additionally, burning wood pellets for heating purposes is an important source of GHG emissions (Tabata 2018). Meanwhile, producing AC from lignocellulosic biomass not only is cost-effective compared to producing it from the other sources, particularly coal, but also it is more valuable than wood pellets (Ukanwa *et al.* 2019). The main limitation on the process of converting woody waste into AC is the losses, which occur in both carbonization and activation stages. Nonetheless, in the wood pellets production process there is not any loss. Fortunately, the conversion ratio in activation stage with fluidized bed reactor was found to be favorable, thus demonstrating the efficiency of the employed method. Fluidized bed reactors can activate carbons appropriately at lower temperatures and residence time compared to other methods such as fixed beds. These types of reactors increase a product's quality by improving the activation process, and it is done by providing appropriate conditions for encountering the activation agent with carbon granules (Couto *et al.* 2016). Thus, designing and configuring a lab-scale fluidized bed reactor, and producing a sample of AC with that to determine its characteristics were judged to be completely logical. The results of the standard tests proved this method's productivity. Nonetheless, LCA technique was employed to criticize turning woody biomass into wood pellets or AC. The assessment process with SimaPro software was performed twice; this was because of having a mutual comparison, which separately presents each product's environmental impacts in the defined indicators. Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), Ozone layer Depletion Potential (ODP), and Photochemical Oxidation Potential (POP) were the assessed environmental indicators. AC and wood pellets' aftereffects on the environment were analyzed through these indicators.

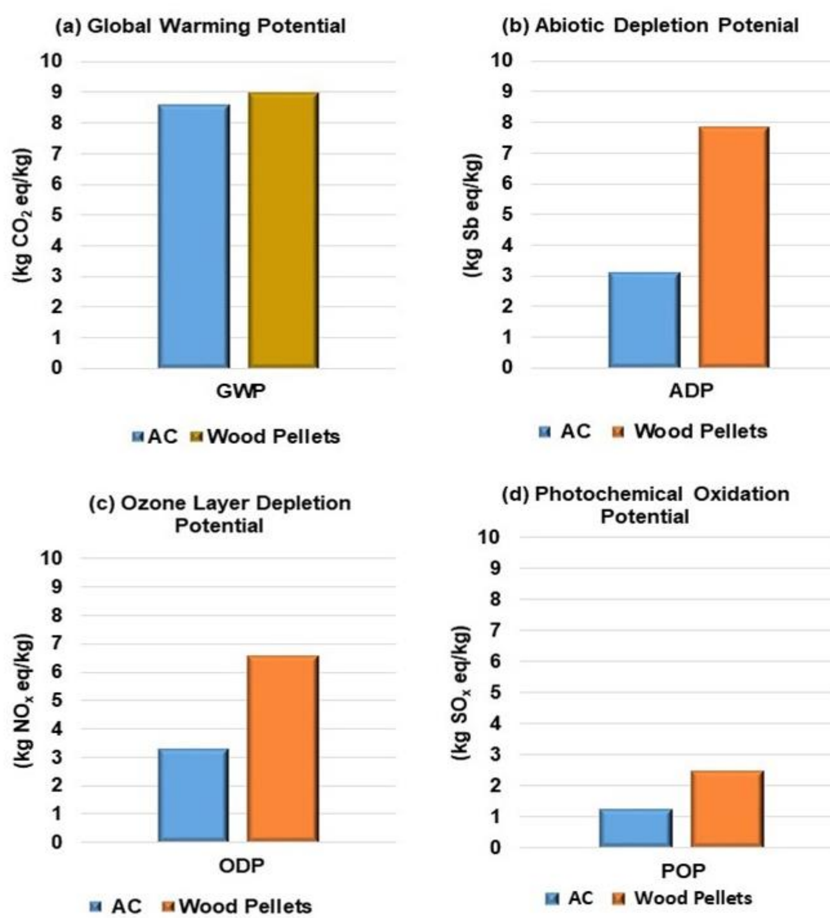

Fig. 4. The results of life cycle assessment

The databases used for importing crucial data into the program were namely: Ecoinvent, GaBi, In Europe: PEF, EPD, GEMIS, and U.S. Life Cycle Inventory (U.S. LCI). The mentioned databases were selected regarding to the used methodology, because selecting a set of regional and global LCA databases is based on the currently used methodologies (Takano *et al.* 2014). The outputs from assessing these indicators are shown in Fig. 4.

Evaluating four indices with the LCA technique allowed for a comparison to be made between the two products. Clearly, converting woody residues into wood pellets for the purpose of having a heat resource leads to severe environmental burdens according to GWP, AP, ODP, and POP indices. Additionally, AC production from the similar waste has a critical effect according to the GWP indicator. However, its ratio is less than wood pellets production. Overall, findings showed that the most and least differences are in ADP and GWP indicators, respectively. To provide a mutual comparison, all indicators are shown together in Fig. 5.

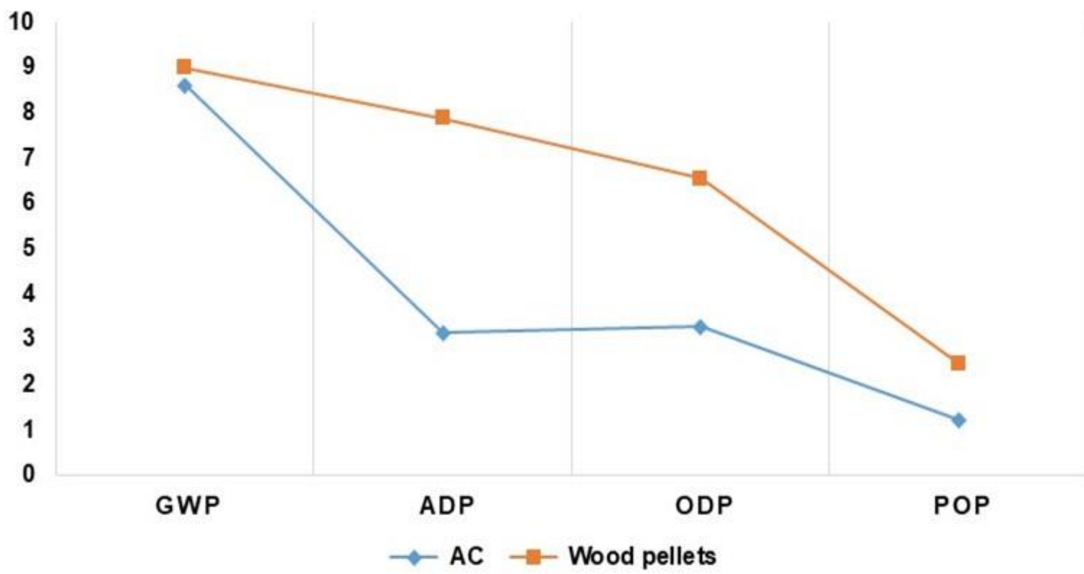

Fig. 5. The mutual comparison of all indicators

Figure 5 indicates the superiority of the AC product relative to wood pellets when considering a range of environmental impact categories. Each product was found to have significant potential in increasing GWP intensity. Nonetheless, this ratio for wood pellets is higher than extracting AC from the woody waste. Because, in spite of this fact that woody biomass is a green source, burning this biomass considerably releases CO_2 into the atmosphere (Schlesinger 2018). Meanwhile, AC is a mature and proven material in adsorbing contaminants, particularly CO_2. In relation to other indicators, the same results were determined, where AC includes less amounts compared to wood pellets. For instance, depleting in quantity of abiotic resources is because of gaseous pollutants' effects, which are derived from burning processes. Gaseous pollutants directly affect air pollution, and this phenomenon is the primary cause that subsequently leads to exacerbate depleting ozone layer and facilitating photochemical oxidation.

The organized amounts in Table 7 are the outputs obtained from LCA evaluation. These numbers were calculated by SimaPro software with considering all inputs and cradle-to-grave methodology.

Table 7. The Indicators' Ratio in the Products' Production And Consumption Cycle

Item	Indicator			
	GWP (Kg CO_2 eq./kg)	**ADP (Kg Sb eq./kg)**	**ODP (Kg CFC 11 eq./kg)**	**POP (Kg SO_x eq./kg)**
AC	8.6	3.123	3.258	1.213
Wood pellets	8.986	7.866	6.534	2.456

Generally, it can be said that producing 1 kg of AC and wood pellets from woody waste includes different environmental impacts in four environmental indicators. The notable difference in emission severity was relevant to ADP indicator, it means during the converting process and consuming period, abiotic resources such as air, ground, and soil are affected by burning wood pellets. In addition, supplying the produced wood pellets to markets or final consumers requires transportation facilities because of its large mass. In addition, these facilities are indispensable in gathering and transmitting the generated waste towards mills, while converting woody waste into AC is planned at local small mills and the final product mass is significantly less than wood pellets. Therefore, there is no need for a transportation system. Transportation plays the main role in ADP, and it is mostly because of distance between the mills and extracted feedstock (Farinha *et al*. 2021).

Similar outputs were found for the ODP and POP indicators, except that CFC eq. and SO_x eq. gaseous pollutants were the base indices to measure the emissions. Burning woody biomass releases contaminants, which affect ozone layer; however, their volume is much less than fossil fuels emissions, and NO_x contributes the most. With respect to the POP indicator, burning wood gives off SO_x, similar to what happens in combusting fossil fuels by vehicles and other consumers. However, its amount is not comparable with fossil fuels. NO_x and VOCs directly affect ozone layer chemistry, and they can decrease its concentration (Bourgeois *et al.* 2021). For this reason, burning biomass and, particularly woody one, is an important precursor in making gaseous pollutants (Crutzen and Andreae 2016). As it is repeatedly mentioned, this energy source is cleaner than fossil fuels. Improving its utilization methods is needed in order to meet environmental goals aiming at a sustainable future.

Overall, by going through the findings, it was indicated that converting apple orchards woody waste into wood pellets is not the best practice to manage them. Producing a sample of AC, analyzing that, determining its characteristics, valorizing, and ultimately assessing its environmental impacts showed us there is a practical alternative for wood pellets production from woody biomass.

This comparison discussed two products that are possible to produce from woody waste. It is clear that a wide range of products and energy can be extracted from this kind of waste. However, in present research, AC and wood pellets were assessed because of an extreme demand for AC, and an increase in orientation towards managing the produced woody waste by converting that into wood pellets at the study place. While converting woody waste into AC presents significant environmental and economic benefits, widespread adoption by farmers could potentially lead to market saturation and a subsequent decline in AC prices. This phenomenon has been observed in other biomass-derived markets, where rapid expansion of production capacity outpaced demand, resulting in price volatility (Alakangas *et al.* 2012). To mitigate such risks, it is essential to assess other biomass-derived products' production potential along with AC and wood pellets. For instance, biochar can be an interesting alternative, because this material is a suitable choice in agricultural activities (*e.g.*, soil amendment) (El-Naggar *et al.* 2019). Therefore, future work should explore strategies to stabilize AC markets, such as diversifying applications or establishing regional cooperatives to regulate supply chains. Further research is also needed to optimize small-scale pyrolysis systems for decentralized production, reducing barriers to entry while maintaining quality control. By addressing these challenges proactively, the proposed approach can offer a resilient pathway for sustainable woody waste management.

CONCLUSIONS

1. Converting apple orchards woody residues into either activated carbon (AC) or wood pellets, was assessed. The main purpose was to develop a means of critically judging which of the two processes provides superior outcomes as a way to manage the generated woody waste in a region.
2. A lab-scale fluidized bed reactor was designed and manufactured and, following that, a sample of AC was produced. This reactor provided better interaction between the carbonized granules and the activation agent (water vapor). Performing standard tests determined the produced AC characteristics. Thereby, it was feasible to estimate the worth of produced AC by considering these specifications.
3. The life cycle assessment (LCA) technique was employed to make a cradle-to-grave assessment. The products were assessed in terms of four environmental indicators, namely global warming potential (GWP), abiotic depletion potential (ADP), ozone layer depletion potential (ODP), and photochemical oxidation potential (POP). The outputs from life cycle assessment analysis demonstrated that converting woody waste into the wood pellets, compared to converting this waste into AC, will give rise to more environmental burdens in all of the studied indicators, and the most difference was in ADP indicator.
4. The results showed that it is logical to criticize the conversion of woody waste into wood pellets when the production of another clean, environmentally friendly, and more efficient substance is feasible.

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