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Techno-economic assessment of wood-based processes with feedstock price scenarios in Austria

Techno-ökonomische Bewertung von Holz-basierten Prozessen mittels Preisszenarien für Rohstoffe in Österreich

Marilene Fuhrmann[a*], Christa Dißauer[a], Christoph Strasser[a], and Erwin Schmid[b]

[a] BEST – Bioenergy and Sustainable Technologies GmbH, Inffeldgasse 21b, 8010 Graz, AT
[b] University of Natural Resources and Life Sciences, Vienna, Department of Economics and Social Sciences, Institute of Sustainable Economic Development, Vienna, AT

[*]*Correspondence to:* marilene.fuhrmann@best-research.eu

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Summary

Woody biomass is a raw material and cost factor for a range of industries in Austria. The aim of this article is to assess impacts of price developments on operating costs of particleboard, combined heat and power (CHP) and synthetic natural gas (BioSNG) production. Three price scenarios have been developed for pulpwood, industrial wood chips and forest wood chips for the period 2021 - 2026. Results show that the share of raw material costs on total operating costs ranges between 24 - 64% for particleboard, 45 - 82% for CHP, and 24 - 63% for BioSNG production.

Keywords: techno-economic assessment, woody biomass, feedstock costs, scenarios

Zusammenfassung

Holzartige Biomasse ist ein wichtiger Rohstoff und ein bedeutender Kostenfaktor für verschiedene Industrien in Österreich. Ziel dieser Studie ist es, die Auswirkungen von unterschiedlichen Preisentwicklungen auf die Betriebskosten der Spanplattenproduktion, der Kraft-Wärme-Kopplung (KWK) und der Erzeugung von „grünem Gas" durch Holzvergasung (BioSNG) zu analysieren. Drei Preisszenarien wurden für Industrierundholz, Hackgut (Sägenebenprodukt) und Waldhackgut für den Zeitraum 2021 - 2026 entwickelt. Die Ergebnisse zeigen, dass sich der Anteil der Rohstoffkosten an den Betriebskosten in einer Bandbreite von 24 - 64% für Spanplatten, 45 - 82% für KWK und 24 - 63% für BioSNG bewegen kann.

Schlagworte: techno-ökonomische Analyse, holzartige Biomasse, Rohstoffkosten, Szenario

1 Introduction

Bioeconomy strategies fostering the utilization of renewable resources in all sectors strongly rely on woody biomass (Giurca, 2020). Higher demand by different industries and sectors has also increased competition as well as implications on sustainable forest management (Tzanova, 2017). In addition, new technologies enter the market and intensify the competition for industrial by-products as well (Bryngemark, 2019). Those by-products, mainly wood chips and sawdust, are readily available at relatively low prices due to a strong sawmill industry, particularly in Austria (Strimitzer et al., 2021; Vienna Stock Exchange, 2015; Timber Online, 2021).

Raw materials are a decisive cost factor in the processing industries as well as material and energy sectors (e.g. Anca-Couce et al., 2020; Grzegorzewska et al., 2020; Wang et al., 2021). To some extent, raw materials can be substituted and the use of by-products might become more attractive (Bryngemark, 2019). Hence, from an economic point of view, industries aim to use cheap raw materials as this has the potential to reduce operating costs. However, raw material prices develop rather dynamic, especially in recent years, and are often interlinked (Fuhrmann et al., 2021). Therefore, the aim of this article is to assess the impact of woody biomass price developments on operating costs of particleboard, combined heat and power (CHP) and synthetic natural gas (BioSNG) production. The particular research questions are:

- What are possible future price developments of pulpwood, industrial wood chips and forest wood chips for the period 2021 - 2026?
- What are the impacts of these price developments on the operating costs of particleboard, combined heat and power, and synthetic natural gas production?

Particleboard is used especially in the furniture sector and represents an important value adding material utilization of industrial wood by-products. Regarding the energy sector, the Austrian "Erneuerbaren-Ausbau-Gesetz" (EAG) aims for Austria to become climate neutral until 2040. Accordingly, it is targeted to increase power generation from biomass by 1 TWh and to reach a level of "green gas" utilization of 5 TWh until 2030 (BMK, 2021). While CHP plants using woody biomass are already established, a promising method to produce "green gas" is the gasification of wood and following synthesis to BioSNG. This technology has already been successfully demonstrated (e.g. Rehling et al., 2011; Thunman et al., 2018), but is not yet operated on an industrial scale. A promising technology is the dual fluidized bed gasification and entrained flow gasification with steam as gasification medium used in the first step. Then, the produced gas is cleaned including the adjustment of the H_2/CO ratio as well as sulfur removal. This results in the clean syngas, which is further used for BioSNG synthesis (Anca-Couce et al., 2021). BioSNG production is considered in this study, because it is seen as a promising technology to contribute to the targets of the EAG.

The article is structured as follows: The next chapter describes data, scenario criteria and employed methods, followed by a presentation of the scenario results, the discussion and conclusion.

2 Data and methods

An Excel-based tool was used to conduct techno-economic assessments of the processes for particleboard production, Combined Heat and Power (CHP) as well as BioSNG production. This tool allows to define a process in terms of technical specifications, which are annual operating hours, lifetime, production capacity (for particleboard production) and fuel input and efficiencies (for CHP and BioSNG). The type and amount of inputs in the process can be selected as well. Accordingly, the investment and operating costs of a process are then calculated using data from the literature (e.g. Grzegorzewska et al., 2020; Anca-Couce et al, 2021; Hofbauer et al., 2020), experts' estimates and empirical values. Raw material costs are obtained from the inputs required according to the technical specifications and the corresponding prices. Prices resulting from the scenarios are used for these calculations. In addition, reference plants are defined with the following specifications. The reference particleboard plant produces 600,000 m³/a with 8,000 operating hours each year and a lifetime of 15 years. The total investment costs are 180 million € (specific investment of 300 €/m³ production capacity). Operating costs include costs for woody biomass, additives, heat and power, personnel, maintenance and others. Maintenance costs are assumed to be 1% of the total investment while the other costs are calculated using specific costs (€/m³) and production capacity (Grzegorzewska et al., 2020).

The CHP plant is defined with a fuel input of 27.8 MW and a production capacity of 5 MW_{el} and 7.5 MW_{th}. It produces 7,800 h/a for an assumed lifetime of 20 years. Total investment costs are 23.2 million € (specific investment of 4,640 €/kW_{el} or 835€/kW fuel input). Operating costs are structured in raw materials as well as personnel, maintenance and others (calculated as share of total investment). This cost structure is based on data of existing plants in Lower Austria.

The reference plant for wood gasification and BioSNG synthesis produces with a fuel input of 42.8 MW and an efficiency of 66%. It is assumed that it runs 8,000 h/a for 25 years. Total investment is assumed to be 114.2 million € (specific investment costs of 2,667 €/kW fuel input). Since BioSNG plants using woody biomass are not operating in such a scale yet, the cost structure is based on experience from smaller pilot plants and feasibility studies. Operating costs include costs for raw materials and operating materials, power, personnel and maintenance as well as disposal costs. Those costs were calculated as share of total investment (Hofbauer et al., 2020).

Raw materials considered in the scenarios are pulpwood, industrial wood chips (i.e., sawmill by-products) and forest wood chips. Single inputs are compared for CHP and

BioSNG production, whereas a comparison is made for 100% pulpwood, 100% industrial wood chips and a 50:50 input mix for particleboard production. Raw material costs have been calculated based on the following material properties:

- Pulpwood: 20% moisture content; LHV 5.1083 kWh/kg-atro[1]; density wet basis 679 kg/m³
- Industrial wood chips: 20% moisture content; LHV 5.1111 kWh/kg-atro; density wet basis 614 kg/m³
- Forest wood chips: 40% moisture content; LHV 4.5759 kWh/kg-atro; density wet basis 742 kg/m³

Based on the plant specifications and raw material properties, required inputs were calculated and, using the scenario prices for 2026, resulted in the depiction of the total cost structures. Since the plants differ in terms of products and capacities, comparability of absolute costs is limited. Therefore, the focus is on the share of raw material costs on total operating costs as well as specific operating costs related to the amounts of outputs. For particleboard, specific costs refer to the volume of products (€/m³), while for CHP the specific costs refer to the total energy content of heat and power sold (€/kWh). In the reference BioSNG process, heat produced is assumed to be used within the process and thus the specific costs are solely related to the energy content of gas produced (€/kWh). For a conversion to a volume basis, a heating value of 10.7 kWh/SCM (standard cubic meter) can be assumed for BioSNG (Rehling et al., 2011).

Raw material prices have been collected using statistical databases and market reports (Table 1). Prices of pulpwood and industrial wood chips are available ex works (EXW) while forest wood chip prices are published delivered at place (DAP). Hence, assumed average transportation costs of 10.7 €/t-atro have been subtracted from forest wood chip prices for a comparability of EXW prices. All prices used are nominal.

Three scenarios were developed for 2021 – 2026 to illustrate a range of possible price developments and price volatilities. Considered raw materials, data sources, time spans of prices used and scenario horizons are shown in Table 1.

Scenario prices were calculated using constant annual developments. The description of the three scenarios – Busi-

Table 1: Raw materials used for the assessments, data sources, and time frames of price availability and scenarios

Raw material	Data source	Available	Scenarios
Pulpwood spruce/fir nominal, ex works	Statistics Austria (2021)	2012/01 – 2021/07	2021/08 – 2026/12
Industrial wood chips nominal, ex works	Vienna Stock Exchange (2015); Timber Online (2021)	2012/01 – 2021/08	2021/09 – 2026/12
Forest wood chips nominal, ex works	Austrian Chamber of Agriculture (2021)	2012/01 – 2021/08	2021/09 – 2026/12

Source: Own compilation.

Table 2: Scenario descriptions, average annual growth rates and raw material price estimation for 2026 (own calculation)

	Baseline	Business as usual	Scenario A	Scenario B
Pulpwood	56.18 €/t-atro	46.43 €/t-atro (- 0.29%)	36.81 €/t-atro (- 0.65%)	85.52 €/t-atro (+ 0.65%)
Industrial wood chips	55.90 €/t-atro	37.35 €/t-atro (- 0.57%)	22.61 €/t-atro (- 1.35%)	127.24 €/t-atro (+ 1.35%)
Forest wood chips	61.80 €/t-atro	55.36 €/t-atro (- 0.17%)	40.65 €/t-atro (- 0.65%)	93.70 €/t-atro (+ 0.65%)

Source: Own calculation.

1 "kg-atro" refers to 1 kg of absolutely dry wood (dry matter).

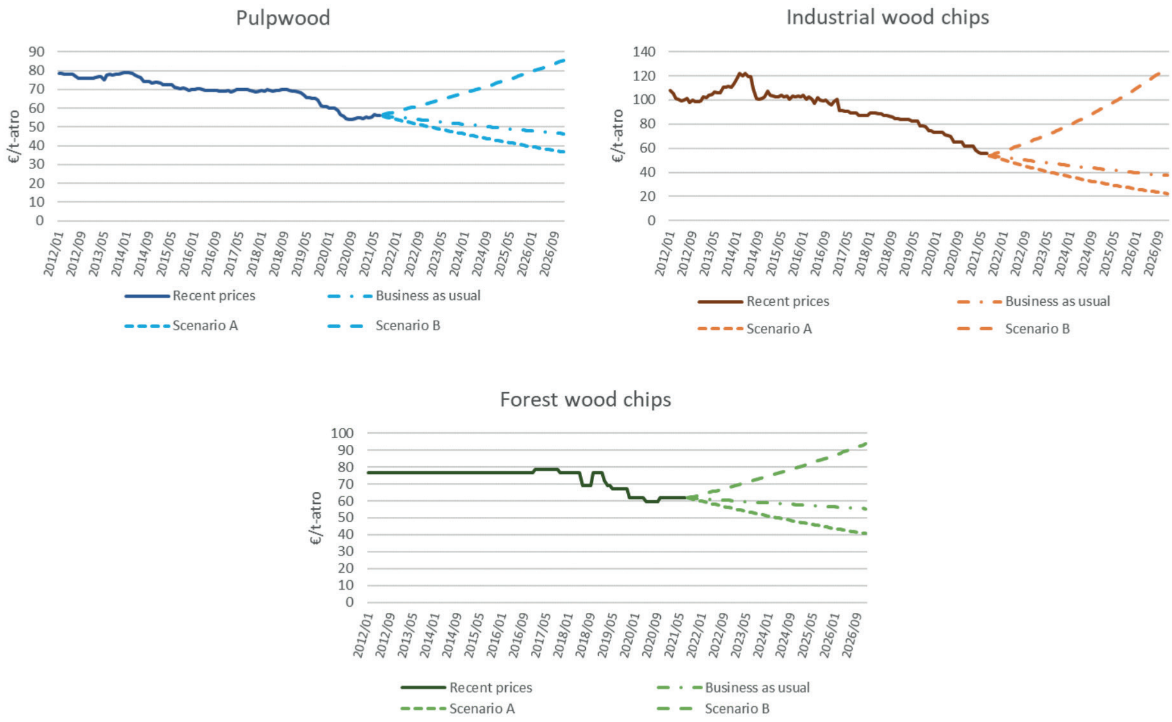
ness as usual, scenario A and scenario B – is given in Table 2, including the annual average growth rate used and the estimated prices for 2026. July 2021 is used as baseline.

3 Results

According to the scenario results, the price decrease of recent years would continue in the BAU and scenario A for all raw materials. Together with scenario B, a broad range of possible developments is covered (see Figure 1), which reflects the volatility of prices and allows to assess the influence of varying prices on operating costs.

In the baseline July 2021, forest wood chip prices are highest (dry matter basis), while pulpwood and industrial wood chip prices are comparable. Recent price developments show a negative trend for prices of all three raw materials. This trend is stronger in the short-term (since 2019, scenario A) than in the mid-term (since 2012, BAU). In contrast, scenario B investigates the case of stabilizing prices with a growth rate as high as in scenario A, but in the opposite direction. In this case, industrial wood chips result in highest prices.
Table 3 lists the required inputs for the three processes used for cost calculations. Forest wood chips, which are consid-

Figure 1: Recent developments of nominal prices of pulpwood, industrial wood chips and forest wood chips and future developments in the scenarios business as usual, scenario A and scenario B



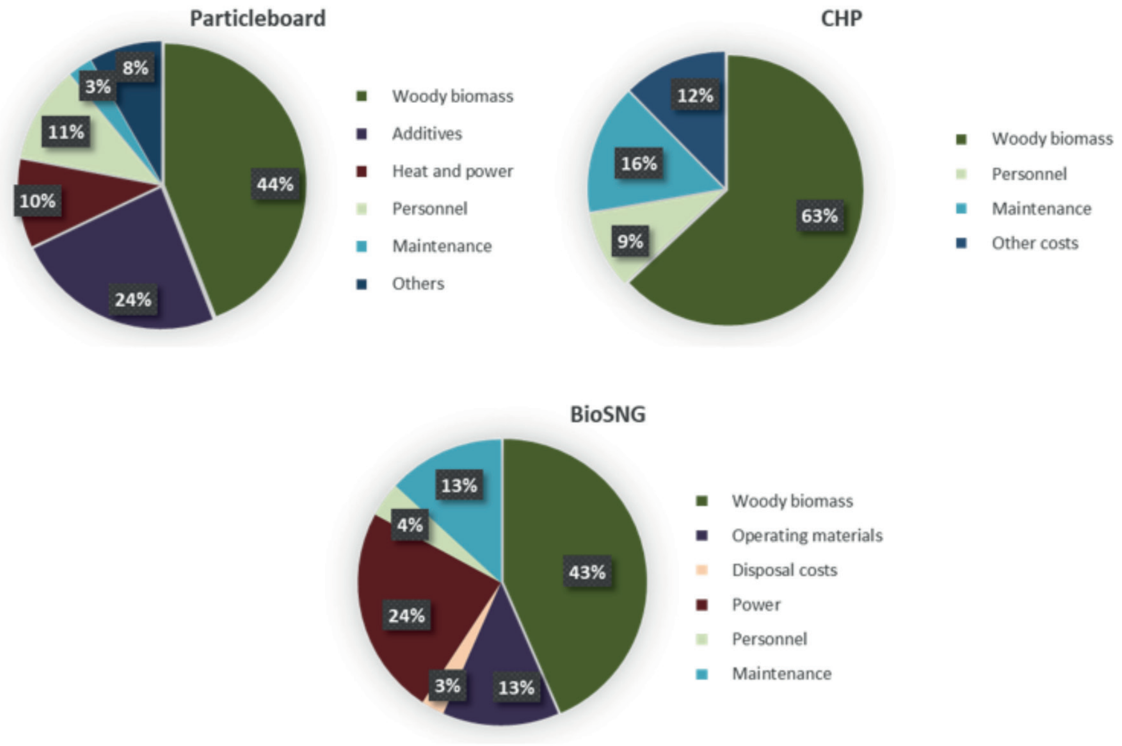
Source: Own calculation and illustration.

Table 3: Inputs required according to the plants' capacities using only single inputs

	Pulpwood	Industrial wood chips	Forest wood chips
Particleboard (600,000 m³)	570,360 t-atro	515,760 t-atro	-
CHP (27.8 MW fuel input)	42,518 t-atro	42,434 t-atro	47,139 t-atro
BioSNG (42.8 MW fuel input)	67,137 t-atro	67,006 t-atro	74,435 t-atro

Source: Own calculation.

Figure 2: Cost structure of particleboard production, CHP and BioSNG using baseline prices for industrial wood chips



Source: Own calculation and illustration.

ered as input in energy processes, require higher amounts as the heating value is lower than of the other inputs (Table 3). In addition, the relatively higher moisture content results in higher prices based on dry matter.
Required inputs based on plant capacities and raw material properties and the respective prices result in the share of operating costs. The baseline structures of operating costs of the processes using 100% industrial wood chips are shown in Figure 2.

Regarding the cost structure of the three processes, the share of raw material costs is highest for CHP. In particleboard production, additives also play an essential role in terms of input volume and costs as well. Consequences of scenario prices applied on the input quantities are shown in terms of total raw material costs and the share of the total operating costs for 2026 (Table 4).

Results in Table 4 show that forest wood chips are associated with the highest costs in the baseline, BAU and scenario A for the energy related processes. The most significant consequences of the scenarios can be observed for industrial wood chips. In scenario B, costs exceed those for forest wood chips. Regarding particleboard production, costs are highest using only pulpwood. However, a mixture of pulpwood and industrial wood chips is usually used in practice (Association of the Austrian Wood Industries, 2020).

Raw material costs are likely to be within the range of 24 - 64% (particleboard), 45 - 82% (CHP) and 24 - 63% (BioSNG) of total operating costs. Accordingly, the specific operating costs (total operating costs from Figure 2 related to one unit produced), shown in Figure 3 would be 80.4 - 170.4 €/m³ (particleboard), 2.2 - 6.7 ct/kWh (heat and power) and 2.8 - 6.0 ct/kWh (BioSNG). The consideration of specific production costs allows to include the investment costs for a comparison of CHP and BioSNG. Those amount to 3.9 - 8.4 ct/kWh (CHP) and 5.9 - 9.0 ct/kWh (BioSNG).

4 Discussion

Price developments in the scenarios cover price volatilities between 2012 and 2019 well. Prices of other raw materials like crude oil, natural gas or construction materials show rather extreme developments in the past year as well (E-Control, 2021a; Statistics Austria, 2022). Using extreme growth rates in the analysis allows to illustrate possible price developments and highlight the consequences for operating costs in wood-based processes in the near future.

The average growth rates used for BAU and scenario A are negative, which is due to the period considered. However, forest wood chip, pulpwood and industrial wood chip prices started rising again from October 2021 onwards. This was already forecasted by Fuhrmann et al. (2021), using an econometric model. Hence, scenario A and B cover a reasonable range of possible price developments while the BAU represents a more likely trend. A broad range can be observed for industrial wood chips based on the highest volatility in 2012-2021. In any case, the definition of scenario time frames has a significant influence on scenario results. Dy-

Table 4: Raw material costs for defined inputs and share of total operating costs calculated for 2026 according to the scenarios business as usual, scenario A and scenario B

Particleboard production				
	Baseline	**Business as usual**	**Scenario A**	**Scenario B**
Pulpwood	32,042,825 €/a	26,479,187 €/a	20,996,947 €/a	48,774,521 €/a
	(47%)	(42%)	(36%)	(57%)
Industrial wood chips	28,830,984 €/a	19,262,812 €/a	11,661,073 €/a	65,625,996 €/a
	(44%)	(34%)	(24%)	(64%)
50/50 mix	30,436,904 €/a	22,871,000 €/a	16,329,010 €/a	57,200,258 €/a
	(45%)	(39%)	(31%)	(61%)
Combined Heat and Power				
	Baseline	**Business as usual**	**Scenario A**	**Scenario B**
Pulpwood	2,388,641 €/a	1,973,898 €/a	1,565,223 €/a	3,635,910 €/a
	(63%)	(63%)	(57%)	(76%)
Industrial wood chips	2,372,085 €/a	1,584,859 €/a	959,421 €/a	5,399,415 €/a
	(63%)	(58%)	(45%)	(82%)
Forest wood chips	2,913,198 €/a	2,609,589 €/a	1,916,051 €/a	4,417,134 €/a
	(68%)	(69%)	(62%)	(79%)
BioSNG				
	Baseline	**Business as usual**	**Scenario A**	**Scenario B**
Pulpwood	3,771,771 €/a	3,116,873 €/a	2,471,557 €/a	5,741,264 €/a
	(43%)	(39%)	(34%)	(54%)
Industrial wood chips	3,745,628 €/a	2,502,562 €/a	1,514,969 €/a	8,525,917 €/a
	(43%)	(34%)	(24%)	(63%)
Forest wood chips	4,600,070 €/a	4,120,658 €/a	3,025,530 €/a	6,974,851 €/a
	(48%)	(45%)	(38%)	(59%)

Source: Own calculation.

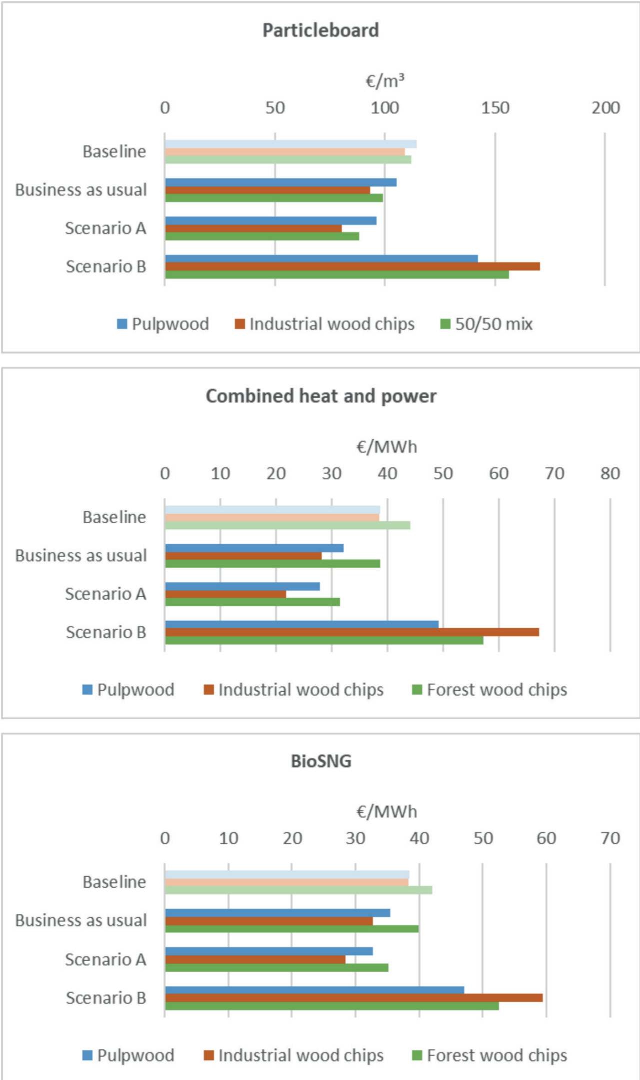
namic price developments make long-term planning difficult for industries. To some extent, variations in prices and corresponding costs can be balanced by switching to other inputs or using mixtures as shown for particleboard production. As demonstrated, a techno-economic assessment by using the Excel tool can provide valuable support for such operative decisions. In the forest-based sector, such assessments usually focus on individual processes (e.g. Grzegorzewska et al., 2020). In contrast, approaches comparing different production systems have already been used in the agricultural sector (for example Heinschink et al., 2016).

In the baseline, operating costs are lowest for industrial wood chips. Due to a relatively high quality, industrial wood chips are used by several industries, like pulp and paper, panel or energy generation processes. An increased utilization of by-products by industries intensifies competition as well, which is expected to further raise raw material prices (Bryngemark, 2019). In scenario B, all prices are assumed to rise again, but growth rates differ. Hence, industrial wood chips result in higher costs than forest wood chips. This can be the case if industries increasingly enforce the use of industrial by-products to foster a circular economy. An opportunity to reduce the pressure on wood utilization is to rely on other materials like agricultural residues or waste streams if possible.

Forest wood chips result in the highest raw material costs in the BAU and scenario A for the energy processes CHP and BioSNG. This can be explained by a lower heating value, as branches and needles are included in the material. Hence, a higher moisture content results in higher prices on a dry matter basis. On a volume basis, latest prices are lowest for forest wood chips (12.2 €/m³), followed by industrial wood chips (14 €/m³) and pulpwood (51.4 €/m³).

Regarding only operating costs, CHP results in higher costs than BioSNG. However, BioSNG is associated with

Figure 3: Specific operating costs (total operating costs excl. investment related to one unit produced; €/m³ for particleboard production and €/MWh for CHP and BioSNG) with raw material scenario prices estimated for 2026 in comparison to the baseline



Source: Own calculation and illustration.

high investment costs, which are reflected in the specific production costs (operating and capital costs related to one kWh produced). The range of specific production costs is higher for BioSNG (5.9 – 9.0 ct/kWh) than for CHP (3.9 – 8.4 ct/kWh). In comparison, the Austrian import price of natural gas was 5.6 ct/kWh in October 2021 (E-Control, 2021a) and has almost doubled until January 2022 (Austrian Energy Agency, 2022). Therefore, BioSNG is not economically feasible with long term average prices of natural gas due to high investments. However, BioSNG production can become competitive at the exceptionally high prices such in 2022. In contrast, the current average price for electricity is around 30 ct/kWh in Austria (E-Control, 2021b). Thus, prices exceed production costs of a CHP plant. However, the CHP production costs are related to the summarized production of both, heat and power and thus are higher only related to power, namely 9.6 – 21.0 ct/kWh_{el}. In this sense, an economically relevant aspect for CHP plants is to have a reasonable heat utilization. This can for example be an industry located nearby the CHP plant, which has constant heat demand such as a sawmill. Developing efficient biomass supply chains can help to reduce costs for CHP and stimulate innovative wood-based processes. A political measure which has the potential to increase the competitiveness of wood-based processes are CO_2-taxes. Those would weaken the current competitive position of relatively cheap fossil alternatives and thereby strengthen biomass utilization (Hofbauer et al., 2020).

5 Conclusion

Raw material prices are characterized by high volatility and dynamic movements, as recent developments have clearly shown. This study has demonstrated the usefulness of such a techno-economic assessment with regard to the effects of price fluctuations. Consequences on supply chains can easily be assessed using the Excel tool with pre-defined specifications. This can support strategic decisions of industries on the one side (e.g. investment decisions) and operative decisions on the other side (e.g. adaptations in feedstocks). The example scenarios and processes have shown which outcome and possible interpretations can be derived. For the calculated examples, particleboard production as material utilization is associated with highest absolute raw material costs considering typical plant capacities. In this case, raw material costs can to some extent be influenced by selecting the inputs and mixtures as well. The share of total operating costs is higher for the CHP plant, which can even reach more than 80%. However, innovative technologies like BioSNG production are suited to process less qualitative raw materials as well, which use is limited for material applications. If all industries rely on the cheapest raw materials, competition will increase as well and is likely to exert pressure on wood as raw material and further influence prices. Therefore, increased use of residues and side streams would be beneficial. This can be supported by the development of efficient biomass supply chains, which also has the potential to reduce industries' production costs, as well as by political measures to strengthen the competitiveness in comparison to fossil-based processes.

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