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OPTIMIZING THE METHOD OF SAWMILL BY-PRODUCT MANAGEMENT: SELECTED METHODOLOGICAL ISSUES

Abstract:

This paper presents a valuation method for sawmill by-products processed into energy. The method includes a set of indexes enabling entrepreneurs who own sawmill by-products to assess the economic viability of processing them into biofuels and energy. The indexes include: the threshold margin, maximum processing costs, maximum purchase price of by-products intended for processing, and minimum sales price of the product acceptable to the producer. A multidimensional analysis of above indexes was performed, and may provide a basis for assessing the economic viability of various methods of wood by-product management as an alternative to selling by-products in an unprocessed condition. As regards energy production, the method takes into account both the use of energy for own purposes and sale of energy to external customers.

Keywords:

renewable energy, sawmill by-products, index-based analysis

JEL Classification: C20, D24, Q42

1. INTRODUCTION

Wood by-products are the most readily available component of solid biofuels, a form of renewable energies which have become increasingly popular in recent years. The reason for the increased interest in renewable energies is the growth of gross energy demand, accompanied by the depletion of traditional energy resources (mainly including fossil fuels) and the increased environmental pollution involved in the consumption of energy from traditional sources. Energy consumption is forecasted to continue growing in the next decades, from 426 EJ (1EJ = 10^{18}J) in 2001 to 599 EJ in 2020 and 657 EJ in 2025 **[**Lewandowski 2010]. These circumstances stimulate interest to search for alternative (more environmentally friendly) sources of energy, as reflected in Union legislation which requires the member states to reach a defined target share of renewable energies in final gross energy consumption by 2020 [Directive 2009]. For Poland, that target is set at 15% but unfortunately, according to recent reports, it is very unlikely to be achieved. The share of renewable energy sources (RES) in final energy consumption in Poland was 11.3% in 2016, which means a decline compared to 2015 (11.7%), 2014 (11.5%) and 2013 (11.4%) [Eurostat 2018]. In Poland, biomass is prevalent (70.7%) in the renewable energy mix [*Energia ze źródeł odnawialnych 2017* (Renewable energies 2017)]. Its most readily available form is wood and wood processing by-products. It is assumed that 100 m^3 of wood harvested in forests generate 64% of wood by-products, including 10 m^3 of bark, 15 m^3 of small wigs, 20 m^3 of larger branches and stump wood, and 19 m^3 of sawdust and chips. The main product, that is lumber, accounts for 36 m^3 out of which only 20-25 m^3 will be used in final product post-processing [Janowicz 2006].

As shown by research, most wood by-products are generated by the sawmill industry [Szostak, Ratajczak, Bidzińska, Gałecka 2004]. Lumber production generates ca. 37.5% of by-products in relation to starting material. In the case of comprehensive processing (production of floorboards, panelling boards, blockboards etc.), the total amount of production residues in relation to round wood ranges from 43% to 58%, depending on final product type and share in the production mix [Mikołajczak 2008].

The growing interest in biomass, resulting in the increase in prices of wood by-products, provides an opportunity to improve the efficiency of sawmills. In addition to selling wood waste to wood-based panel producers and to the pulp and paper or energy industries, the entrepreneurs consider another option which consists in the onsite processing of waste. The processing of sawdust, chips or pieces of waste into such products as wood briquettes, pellets or directly into energy is a way to increase their value and improve the economic viability of the undertaking.

The decision to launch the production of any product made of wood by-products requires a detailed analysis which includes identifying the raw material base (processing volume, scope of wood processing operations, type of production residues), required capital expenditure and the potential sales volume of specific products at a given price. These figures affect not only the decision itself to engage into processing activities but also the degree and method of waste processing, the productivity of manufacturing equipment and the size of additional employment. Another aspect of the analysis is to determine the value of different types of wood by-products which are suitable for processing into selected products while also taking account of unit production costs and other factors referred to above.

The objective of the article was developing a method of optimizing the means of utilization of sawmill by-products.

2. METHODOLOGY

This paper presents a method for maximizing the utilization of sawmill by-products. It is a part of a broader research on the optimization of wood biomass use. The method allows to determine the value of sawmill by-products processed into biofuels (wood briquettes, pellets) and energy. The essential part of this method is a multidimensional analysis of the economic viability of various methods of wood by-product management as an alternative to selling by-products in an unprocessed condition. This is done with the use of the following indexes:

– threshold margin (m_{gr}): the maximum attainable margin at a defined level of: unit processing costs; sales price of unprocessed by-products; and product sales price accepted by the market;

– maximum price of sawmill by-products: the price which, if exceeded (under the assumption that m_{gr} = 0 and other variables have their values set), makes it economically unviable for a producer who does not own sawmill by-products to purchase and process them;

– maximum unit processing costs, including transport costs, i.e. costs which represent the break-even point for production under the assumption that margin m_{gr} = 0, and at a set sales price of the product;

– maximum unit transport costs (unit processing costs excluded);

– minimum sales price of the product acceptable to the producer, i.e. the price which, if not attained at a set level of processing costs and at m_{gr} = 0, will make the processing of by-products economically unviable.

3. VALUE OF SAWMILL BY-PRODUCTS PROCESSED INTO BIOFUELS AND ENERGY

Pellets and wood briquettes production

The producer's unit profit from production residue processing into woodfuels may be expressed with the following equations:

$$Z_j = P_j - K_j - p\,(P_j - K_j) \tag{1}$$

$$Z_j = c_j\, m_j \tag{2}$$

where:

P_j – unit revenue from sales of a woodfuel [PLN/t],
K_j – unit production cost of a woodfuel [PLN/t],
p – income tax (CIT) rate,
c_j – unit price of a woodfuel [PLN/t],
m_j – assumed level of net margin, m_j: {0.01; 0.05; ... 0.15}.

The following results from comparing the sides of equations (1) and (2):

$$c_j\, m_j = P_j - K_j - p\,(P_j - K_j) \tag{3}$$

$$c_j\, m_j = (P_j - K_j)\,(1 - p) \quad : (1 - p) \quad \Big| \tag{4}$$

$$\frac{c_j m_j}{1 - p} = P_j - K_j \tag{5}$$

Sales revenue equals to the unit price multiplied by the number of product units sold: $P_n = c_{jn}$. Therefore, with $n = 1$, the unit revenue will be:

$$P_j = c_j \tag{6}$$

In turn, unit cost is composed of:

$$K_j = k_{jp} + k_{jt} + ak_{jmat.} \tag{7}$$

where:

k_{jp} – unit cost of processing by-products into a specific woodfuel, including other operational costs [PLN/t];
k_{jt} – unit cost of transporting by-products to the processing site (if different than the location where it was generated) [PLN/t],
k_{jmat} – basic material cost; in this case: by-product value, referred to later as $w_{pub.}$ [PLN/m^3],
a – quantity of basic material (by-product) required to produce one unit of a specific woodfuel (raw material consumption rate) [m^3/t].

Expressions (6) and (7) are substituted into equation (5) which is afterwards transformed to isolate the values of wood by-products processed into any woodfuel (13):

$$\frac{c_j m_j}{1-p} = c_j - (k_{jp} + k_{jt} + aw_{pub}) \tag{8}$$

$$\frac{c_j m_j}{1-p} = c_j - k_{jp} - k_{jt} - aw_{pub} \tag{9}$$

$$aw_{pub} = c_j - \frac{c_j m_j}{1-p} - k_{jp} - k_{jt} \tag{10}$$

$$aw_{pub} = c_j \left(1 - \frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \quad : a \qquad \Big| \tag{11}$$

$$w_{pub} = \frac{1}{a}\left[c_j \left(1 - \frac{m_j}{1-p}\right) - k_{jp} - k_{jt}\right] \tag{12}$$

Ultimately, all types of wood by-products processed into any woodfuel can be valued with the following equation:

$$W_{pi} = \frac{1}{a_{pi}}\left[c_{jp}\left(1 - \frac{m_j}{1-P}\right) - k_{pi} - k_{ti}\right] \qquad [\mathrm{PLN/m^3}] \tag{13}$$

where:

W_{pi} – Value of wooden residue being processed into any woodfuel [PLN/m^3],
p – number of the type of by-product being converted, i ϵ <1, n>,
i – the type of generated woodfuel, p ϵ <1, n>,
a_{pi} – the ratio of material intensity when processing the given by-product „*i*” into woodfuel „*p*” [m^3/t],
c_{jp} – unit sales price of the fuel ”*p*” generated while processing by-products [PLN/t],
m_j – assumed net profit margin level, satisfactory for the producer, m_j: {0,01; 0,05; ... 0,15},
P – Corporate Income Tax (CIT),
k_{pi} – cost per unit of processing wooden residue including the remaining operational cost per unit [PLN/t],
k_{ti} – cost of transporting a unit of wooden residue to the place where it will be processed in case it takes place outside the place of its origin [PLN/t],

The total value of sawmill by-products which may be used by sawmills by processing them into any biofuel (pellets and wood briquettes) can be calculated as:

$$W = \sum_{i=1}^{n} u_{pubi} \frac{1}{a_{pi}}\left[c_p\left(1 - \frac{m_j}{1-p}\right) - k_{pi} - k_{ti}\right] \qquad [\mathrm{PLN/m^3}] \tag{14}$$

where:

u_{pubi} – share of by-product "i" in the volume processed into pellets.

Processing into energy

The processing of sawmill by-products into energy generates a unit profit which may be expressed with the following equations:

$$Z_j = P_j - K_j - p\,(P_j - K_j) \qquad \text{[PLN/GJ]} \qquad (15)$$

$$Z_j = c_j m_j\,, \qquad \text{[PLN/GJ]} \qquad (16)$$

where:

P_j – unit revenue from energy sales (or, alternatively, the savings resulting from replacing a fuel with wood production residue) [PLN/GJ],
K_j – energy production unit cost [PLN/GJ],
p – income tax (CIT) rate,
c_j – unit price of energy from combustion of by-products [PLN/GJ],
m_j assumed level of net margin, m_j: {0.01; 0.05; ... 0.15}.

The following results from comparing the sides of equations (15) and (16):

$$c_j m_j = P_j - K_j - p\,(P_j - K_j) \qquad (17)$$
$$c_j m_j = (P_j - K_j)\,(1 - p) \quad : (1 - p) \quad \Big| \qquad (18)$$
$$\frac{c_j m_j}{1-p} = P_j - K_j \qquad (19)$$

Sales revenue equals to the unit price multiplied by the number of energy units sold: $P_n = c_{jn}$. Therefore, with $n = 1$, the unit revenue will be:

$$P_j = c_j \qquad (20)$$

In turn, the unit cost of energy resulting from the combustion of a specific waste type may be determined as follows:

$$K_j = \frac{k_{jp} + k_{jt} + k_{mat}}{gQ_{dw}} \qquad \text{[PLN/GJ]} \qquad (21)$$

where:

k_{jp} – unit cost of processing into energy a given type of by-product along with the remaining unit operating costs [PLN/m^3],
k_{jt} – unit cost of transporting a given type of by-product to the place of its processing into energy [PLN/m^3],

k_{mat} – unit cost of the combusted by-product type w_{pub} [PLN/m^3],
Q_{dw} – calorific value of the combusted by-product type of a specific relative humidity w_w [GJ/t],
g – bulk density of the type of by-product being burnt [t/m^3],

Expressions (20) and (21) are substituted into equation (19) which is afterwards transformed to isolate the values of wood waste processed into energy w_{pub} (25): At the same time, an assumption is made that upon attaining the expected margin level m_j, the unit cost of the combusted type of waste k_{mat} represents its value w_{pub}.

$$\frac{c_j m_j}{1-p} = c_j - \frac{k_{jp} + k_{jt} + w_{pub}}{g Q_{dw}} \quad \Big| \text{ x } gQ_d \qquad k_{mat} = w_{pub} \tag{22}$$

therefore:

$$\frac{c_j m_j g Q_{dw}}{1-p} = c_j g Q_{dw} - k_{jp} - k_{jt} - w_{pub} \tag{23}$$

$$w_{pub} = c_j g Q_{dw} - \frac{c_j m_j g Q_{dw}}{1-p} - k_{jp} - k_{jt} \quad \text{[PLN/m}^3\text{]} \tag{24}$$

$$w_{pub} = c_j g Q_{dw}\left(1 - \frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \quad \text{[PLN/m}^3\text{]} \tag{25}$$

Q_{dw} is then substituted with expressions determined based on the author's own calculations [Mikołajczak 2011] and other previous research [Krzysik 1978, Bogusz, Glijer, Sujeta, Świeciak 1991]:

$$Q_{dw} = \frac{19{,}5 - 2{,}5w_0}{1 + w_0} \text{ [MJ/kg]} \quad \text{(a)} \qquad \text{or} \qquad Q_{dw} = 19{,}5 - 22w_w \text{ [MJ/kg]}$$
(b)

equation (25) takes the following form:

$$w_{pub} = c_j g \frac{19{,}5 - 2{,}5w_o}{1 + w_o}\left(1 - \frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \quad \text{[PLN/m}^3\text{]} \tag{26a}$$

or:

$$w_{pub} = c_j g (19{,}5 - 22w_w)\left(1 - \frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \quad \text{[PLN/m}^3\text{]} \tag{27b}$$

Based on formula (25), it was ultimately assumed that the value of a specific type of waste processed into energy may be assessed as follows:

$$W_{ei} = c_{je} g \frac{19{,}5 - 2{,}5w_0}{1 + w_0}\left(1 - \frac{m_j}{1 - p}\right) - k_{pi} - k_{ti} \qquad [\mathrm{PLN/m^3}] \qquad (28a)$$

or, alternatively:

$$W_{ei} = c_{je} g (19{,}5 - 22w_w)\left(1 - \frac{m_j}{1 - p}\right) - k_{pi} - k_{ti} \qquad [\mathrm{PLN/m^3}] \qquad (29b)$$

where:

W_{ei} – value of a certain type of wood waste of „i” number when processed into energy [PLN/m^3],
i – number of type of wood waste product being processed, i ϵ <1, n>,
Q_{wi} – fuel value i- of this type of by-product of a given moisture level wo [GJ/t],
c_{je} – unit sales price of energy obtained from burning by-products [PLN/GJ],
w_w – relative moisture of the type of by-product being burnt,
w_o – absolute moisture of the type of by-product being burnt,
k_{pi} – unit cost of processing into energy a given type of by-product of „i” number along with the remaining unit operating costs [PLN/m3],
k_{ti} – unit cost of transporting a given type of by-product of „i” number to the place of its processing into energy [PLN/m3],

When using the equations for woodchips, as proposed by Danish sources [Serup, Kofman et al. 2005]: $Q_{dw} = 19{,}2 - 0{,}2164 w_w$ (pine, spruce, birch) i $Q_{dw} = 19{,}0 - 0{,}2144 w_w$ (hardwood), the formulas will take the following form:

$$W_{ei} = c_{je} g (19{,}2 - 0{,}2164w_w)\left(1 - \frac{m_j}{1 - p}\right) - k_{pi} - k_{ti} \qquad [\mathrm{PLN/m^3}] \qquad (30)$$

$$W_{ei} = c_{je} g (19{,}0 - 0{,}2144w_w)\left(1 - \frac{m_j}{1 - p}\right) - k_{pi} - k_{ti} \qquad [\mathrm{PLN/m3}] \qquad (31)$$

Similarly to formula (28a), the total value of wood by-products W_e which may be used by sawmills by processing them into energy may be calculated as:

$$W_{ei} = \sum_{i=1}^{n} u_{pubi} c_{je}\, g \frac{19{,}5 - 2{,}5w_0}{1 + w_0}\left(1 - \frac{m_j}{1 - p}\right) - k_{pi} - k_{ti} \qquad [\mathrm{PLN/m3}] \quad (32)$$

where:

u_{pubi} – share of by-product “i” in the volume processed into energy.

4. MULTIDIMENSIONAL BENCHMARK OF ECONOMIC VIABILITY OF VARIOUS METHODS OF SAWMILL BY-PRODUCT MANAGEMENT

Pellets and wood briquettes production

The ratio of value to price in an unprocessed condition allows to assess the viability of processing sawmill by-products into biofuels and energy at various levels of net profit margin set as assumptions. The formula needs to be transformed adequately in order to determine the maximum attainable margin, maximum processing costs and the price of “waste” which, if not exceeded, makes its purchase an economically viable project.

Using the relation (8), one may determine threshold ***maximum margin – m_{gr}*** (35), that will enable us to evaluate the profitability of processing sawmill by-products as an alternative for their direct sales.

$$\frac{\left(c_{jp}m_{gr}\right)}{(1-P)} = c_{jp} - \left(k_{pi} + k_{ti} + a_{pi}W_{pi}\right) \qquad m_j = m_{gr} \tag{33}$$

It is then assumed that the value of those by-products being processed into the fuel under analysis equals the price which may be obtained while selling them unprocessed ($W_{pi} = c_{pub}$).

$$c_{jp}m_{gr} = (1-p)\left(c_{jp} - k_{pi} - k_{ti} - a_{pi}c_{pub}\right) \tag{34}$$

Thus threshold margin is understood as the maximum possible margin using specific cost of production, determined sales price of unprocessed by-product, as well as the price acceptable by the market:

$$m_{gr} = \frac{1}{c_{jp}}(1-p)\left(c_{jp} - k_{pi} - k_{ti} - a_{pi}c_{pub}\right) \tag{35}$$

where:

c_{pub} – unit sales/purchase price of a by-product type.

In case of determining threshold margin at $m_{gr} = 0$, one may determine ***maximum price of by-products – $c_{ub\ max}$*** (39), beyond which the entrepreneur who is not in the possession of those by-products is unable to purchase and process them while simultaneously making profit.

$$\frac{1}{c_{jp}}(1-p)\left(c_{jp} - k_{pi} - k_{ti} - a_{pi}c_{pub}\right) = 0 \qquad c_{pub} = c_{ub\ max} \tag{36}$$

For the equation (36) to be true the following conditions have to be fulfilled:

$c_{jp} \neq 0$ and: $1-p = 0$ or $c_{jp} - k_{pi} - k_{ti} - a_{pi}c_{ub\,max} = 0$

Because p is constant and equals 0,19, equation (36) is true, when:

$$c_{jp} - k_{pi} - k_{ti} - a_{pi}c_{ub\,max} = 0 \qquad (37)$$

$$a_{pi}c_{ub\,max} = c_{jp} - k_{pi} - k_{ti} \qquad (38)$$

Thus the level of wooden by-products price up to which the entrepreneur is efficiently able to purchase and process them into the product sold at price c_{jp}, is as follow:

$$c_{ub\,max} = \frac{c_{jp} - (k_{pi} + k_{ti})}{a_{pi}} \qquad [\text{PLN/m}^3] \qquad (39)$$

where:

$c_{ub\,max}$ – maximum unit purchase price of a specific by-product in an unprocessed condition, intended to be processed into woodfuel [PLN/m^3],

c_{jp} – unit sales price of by-products processed into fuel [PLN/t].

Equation (36) also allows for determining the threshold level of production efficiency as ***maximum unit costs of processing*** wooden by-products, ***including cost of transport – ($k_{p\,max}$ + $k_{p\,min}$)***, at margin $m_{gr} = 0$ and the defined sales price of the product generated based on them (40):

$$k_{p\,max} + k_{t\,max} = c_{je} - a_{pi}c_{pub} \qquad k_{pi} + k_{ti} = k_{p\,max} + k_{p\,min} \qquad (40)$$

and the ***minimum***, acceptable for *the* ***producer sales price*** of the generated fuel **– $c_{p\,min}$** (41):

$$c_{p\,min} = a_{pi}c_{pub} + k_{pi} + k_{ti} \qquad [\text{PLN/t}] \qquad (41)$$

Energy production

Just like in the case of processing by-products into biofuels, the method for valuating sawmill by-products processed into energy allows to comprehensively analyze this activity in terms of economic viability.

Assuming as the starting point the formula (42):

$$W_{ei} = c_{je}g\frac{19{,}5 - 2{,}5w_o}{1 + w_o}\left(1 - \frac{m_j}{1-p}\right) - k_{pi} - k_{ti} \qquad [\text{PLN/m}^3] \qquad (42)$$

As the result of adequate conversions and with the assumption that: $m_j=0$, one may determine ***the lowest, possible to be accepted by the producer sales price of generated energy – $c_{e\,min}$*** (45):

$$W_{ei} = c_{je} g \frac{19{,}5 - 2{,}5 w_o}{1 + w_o} - k_{pi} - k_{ti} \qquad [\text{PLN/m}^3] \qquad (43)$$

$$c_{je} = \frac{(W_{ei} + k_{pi} + k_{ti})(1 + w_0)}{g(19{,}5 - 2{,}5 w_0)} \qquad [\text{PLN/GJ}] \qquad (44)$$

Consequently assuming further that the profitability of conversion is conditioned by the equation: $W_{ei} = c_{pub}$ (the value of by-products being processed into energy cannot be lower than the price of purchasing or selling them unprocessed), relation (44) will look as follows:

$$c_{e\min} = \frac{(c_{pub} + k_{pi} + k_{ti})(1 + w_0)}{g(19{,}5 - 2{,}5 w_0)} \qquad [\text{PLN/GJ}] \qquad (45)$$

When energy production constitutes company side-production, based only on its own raw material in equation (45) cost of transport is ignored k_{ti}:

$$c_{e\min} = \frac{(c_{pub} + k_{pi})(1 + w_0)}{g(19{,}5 - 2{,}5 w_0)} \qquad [\text{PLN/GJ}] \qquad (46)$$

Analogically as in case of converting wooden by-products into pellet and briquettes, one may determine ***maximum margin – m_{egr}*** (50), facilitating the profitability evaluation of converting those materials into energy. Then one uses the relation (22), at the same time assuming that the value of by-products converted into energy equals the price which can be realized when selling them unprocessed ($W_{ei} = c_{pub}$).

$$\frac{c_{je} m_j}{1 - p} = c_{je} - \frac{k_{pi} + k_{ti} + W_{ei}}{g Q_{wi}} \quad \text{x } (1 - p) \quad \Big| \qquad (47)$$

$$c_{je} m_{egr} = (1 - p)\left(c_{je} - \frac{k_{pi} + k_{ti} + c_{pub}}{g Q_{wi}}\right) \quad \Big| c_{je} \qquad (48)$$

where:

m_{egr} – maximum margin – maximum level of margin to be realized at given remaining variables,

Q_{wi} – fuel value i-that type of by-product of a certain moisture content w_o [GJ/t],

Because fuel value of dump wood Q_{wi} of absolute moisture w_o may be expressed by the equation:

$$Q_{wi} = \frac{19{,}5 - 2{,}5 w_0}{1 + w_0} \qquad [\text{MJ/kg}] \qquad (49)$$

hence following adequate conversions, the level of maximum margin will amount to:

$$m_{egr} = \frac{1}{c_{je}}(1-p)\left(c_{je} - \frac{(k_{pi}+k_{ti}+c_{pub})(1+w_0)}{g(19{,}5-0{,}25w_0)}\right) \tag{50}$$

Assuming maximum margin level at $m_{egr} = 0$, allows to determine the ***maximum price of wooden by-products*** – ***$c_{eub\ max}$*** (55), beyond which an entrepreneur who is not their administrator is not able to purchase them and convert into energy with a profit.

$$\frac{1}{c_{je}}(1-p)\left(c_{je} - \frac{(k_{pi}+k_{ti}+c_{pub})(1+w_0)}{g(19{,}5-0{,}25w_0)}\right) = 0 \qquad c_{pub} = c_{eub\ max} \tag{51}$$

For the equation (51) to be true the following conditions have to be fulfilled:

$c_j \neq 0$ and: $1 - P = 0$ or $c_{je} - \frac{(k_{pi}+k_{ti}+c_{eub\ max})(1+w_0)}{g(19{,}5-0{,}25w_0)} = 0$

Because P is a fixed number and equals 0,19, equation (51) will be true when:

$$c_{je} - \frac{(k_{pi}+k_{ti}+c_{eub\ max})(1+w_0)}{g(19{,}5-0{,}25w_0)} = 0 \tag{52}$$

$$\frac{(k_{pi}+k_{ti}+c_{eub\ max})(1+w_0)}{g(19{,}5-0{,}25w_0)} = c_{je} \qquad \Big|\ \text{x}\ g\frac{19{,}5-2{,}5w_0}{1+w_0} \tag{53}$$

$$k_{pi}+k_{ti}+c_{je} = c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0} \tag{54}$$

hence the price level of wooden by-products, up to which it is still profitable for the producer to buy them and convert into energy, sold at c_{je} price equals:

$$c_{eub\ max} = c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0} - k_{pi} - k_{ti} \qquad [\text{PLN/m}^3] \tag{55}$$

where:

$c_{eub\ max}$ – maximum purchase price of the raw material to be converted [PLN/m3],

Equation (108) also allows us to determine maximum unit costs of processing wooden by-products directly into energy, including cost of transport, assuming margin at mgr = 0 and at a given price of selling energy unit c_{je}:

$$k_{p\max} + k_{t\max} = c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0} - c_{pub} \qquad k_{pi}+k_{ti} = k_{p\ max} + k_{p\ min} \qquad [\text{PLN/m}^3] \tag{56}$$

Presentation of indicators facilitating a versatile profitability analysis of using all types of sawmill by-products to generate ecological fuels and energy is drawn in table 1.

Table 1: Elements of ratio analysis of profitability of converting sawmill by-products into wooden fuels and energy

Ratio	Wooden fuel[1)]	Energy[2)]
Value of by-product in conversion [PLN /m³]	$W_{pi}=\frac{1}{a_{pi}}\left[c_{jp}\left(1-\frac{m_j}{1-P}\right)-k_{pi}-k_{ti}\right]$	$W_{ei}=c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0}\left(1-\frac{m_j}{1-p}\right)-k_{pi}-k_{ti}$
Maximum margin	$m_{gr}=\frac{1}{c_{jp}}(1-p)(c_{jp}-k_{pi}-k_{ti}-a_{pi}c_{pub})$	$m_{egr}=\frac{1}{c_{je}}(1-p)\left(c_{je}-\frac{(k_{pi}+k_{ti}+c_{pub})(1+w_0)}{g(19{,}5-0{,}25w_0)}\right)$
Maximum unit costs of conversion including transport [PLN/t][1)] [PLN/m³][2)]	$k_{p\,max}+k_{t\,max}=c_{je}-a_{pi}c_{pub}$	$k_{p\max}+k_{t\max}=c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0}-c_{pub}$
Maximum costs of transport per unit [PLN/t][1)] [PLN/m³][2)]	$k_{t\,max}=c_{je}-a_{pi}c_{pub}-k_{p\,max}$	$k_{t\,max}=c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0}-c_{pub}-k_{pi}$
Minimum selling price of finished goods, which can be accepted by producer [PLN/t][1)] [PLN/GJ][2)]	$c_{p\min}=a_{pi}c_{pub}+k_{pi}+k_{ti}$	$c_{e\min}=\frac{(c_{pub}+k_{pi}+k_{ti})(1+w_0)}{g(19{,}5-2{,}5w_0)}$
Maximum purchase price of raw materials for conversion [PLN/m³]	$c_{ub\max}=\frac{c_{jp}-(k_{pi}+k_{ti})}{a_{pi}}$	$c_{eub\,max}=c_{je}g\frac{19{,}5-2{,}5w_0}{1+w_0}-k_{pi}-k_{ti}$

Source: authors' own elaboration

5. CONCLUSION

The formula for a rationalized use of the stream of sawmill by-products determines the value of their particular types, and therefore allows sawmilling companies to choose the most profitable way of using production residues. Also, it provides a basis for determining the target utilization patterns of wood residue. The method may be used as well to assess the economic viability of production as the core activity of entrepreneurs who purchase raw materials on the market.

For sawmilling companies, determining the value of wood by-products processed into energy is a way to assess the economic viability of replacing a specific energy carrier type with wood production residues. In turn, entrepreneurs who use wood biomass to produce energy and sell it to the power grid may rely on this method to determine the attainability of the expected net profit margin and to identify the lowest acceptable purchase price of energy paid by the power plant.

The multidimensional benchmark of economic viability of various methods of sawmill by-product management consists in determining the following: the threshold margin; maximum processing costs; maximum purchase price of by-products intended for processing; maximum distance traveled to source raw material; and minimum sales price of the product acceptable to the producer.

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