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# ECONOMIC ANALYSIS OF THE COLLECTION AND TRANSPORTATION OF PRUNED BRANCHES FROM ORCHARDS FOR ENERGY PRODUCTION

*This economic analysis contains a case study for a 100 ha apple orchard where a pruning-to-energy (PtE) strategy is employed. Technical aspects of pruned biomass harvesting in apple orchards are outlined, with emphasis on the efficient harvesting of pruning residues using a dedicated baling machine. Economic aspects are approached using economic performance metrics such as the net present value (NPV) and internal rate of return (IRR). It is found, for a 10-year project on the 100 ha orchard, that the NPV is €5650, the IRR is 8.71% and the payback time is about 8.0 years. Sensitivity analysis revealed that the economic metrics are highly influenced by the quantity of prunings, orchard area, and the price of pruning residues at the final user. The distance from the orchard to the final user (6 km in the analysed case) and orchard labour costs are both less impactful. The analysis shows that pruned biomass harvesting is technologically feasible in apple orchards, while the obtained values of the economic metrics indicate the economic feasibility of such bioenergy solutions.*

**Keywords:** pruning, apple orchard, biomass harvesting, energy, economic analysis

## Introduction

The scarcity of fossil fuels for electricity and heat production, together with needs for environmentally friendly development, make sustainable energy provision to meet existing and future demands one of the main concerns for growing European economies [Eurostat 2015]. Therefore, more and more attention has been paid to new directions of renewable energy harvesting, especially from sources that are available locally while meeting the demands of

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specific regions. These conditions might be fulfilled by the use of biomass residues obtained from the pruning operations carried out regularly in fruit plantations. In Europe, the most common types of plantations are those of grapes, olives and apples [Eurostat 2016], whose geographical distribution depends on factors such as weather conditions, climate, soil properties, and local traditions.

In Poland, all of the abovementioned factors are favourable for apple cultivation. Consequently, that country has ca. 350,000 hectares of orchards, of which more than 50% are apple orchards [GUS 2016]. This crop requires annual pruning to maintain good fruit productivity, and thus generates a substantial amount of wooden residues [Rabcewicz et al. 2010; Dyjakon et al. 2016], which must be removed from the orchard or mulched *in situ* [Romański et al. 2014]. Removal of branches from the inter-row area significantly reduces the risk of puncturing the tyres of the tractor during its further use in the orchard. The development of feasible techniques for using these problematic residues would allow wastes to be converted into valuable products and used to achieve additional financial revenues, and would ultimately reduce the operating and maintenance costs of orchards [Spinelli and Picchi 2010]. An interesting option for pruned biomass is its utilization for energy purposes, which has many clear advantages. Among the positive features of pruning-to-energy (PtE) is the fact that it does not compete with food production. It can also reduce $CO_2$ emissions [Bertrand et al. 2014], and the flue gas emissions from pruned biomass combustion are low, not exceeding environmental emissions thresholds [Carvalho et al. 2013]. Moreover, PtE supports the achievement of EU targets in heat and/or electricity production from renewable energy sources (RES) and the development of a decentralized energy market (The Climate and Energy Package, Directive 2009/28/EC). Finally, if the pruned biomass is burned locally in domestic or middle-size boilers, it increases regional energetic independence and supports social integration.

However, implementation of the PtE strategy requires good logistic performance [Bosona et al. 2016]. The total logistic costs of the whole chain, including pruned biomass harvesting, storage and transportation to the final consumer, must be lower than the revenue from sale of the biomass. Technologies used in the implementation of PtE include chipping or baling. Many manufacturers offer specialized machinery and devices for the harvesting and treatment of pruned biomass. Such machines may be designed for a single operation (pickup, baling, chipping, collecting or packing) or may be sophisticated systems able to perform all of the actions necessary to prepare the final product for storage or transportation to the final consumer [Spinelli et al. 2010; Magagnotti et al. 2013; Frąckowiak et al. 2016]. Storage is also an important part of the logistic chain. Different storage options may be applied: open air storage, undercover storage, tank storage, storage with drying, etc. The material may be stored at the orchard, at the final user, or in an intermediate location [Rentizelas et al. 2009]. A crucial issue in the PtE logistic chain is transportation. The distance between the orchard and the final consumer, as well as the quantity of pruned biomass to be transported, are of critical importance in the estimation of the total costs of the supply chain [Alfonso et al. 2009]. Finally, the price of the pruned biomass delivered to the user as a source of heat is a decisive parameter regarding the sustainability of biomass utilization for energy purposes. It should fulfil customer requirements and be competitive with respect to other fuels available on the market [Asztemborski and Wnuk 2015].

As yet there are no published data relating to the final cumulative costs of the use of pruning residues for energy purposes including all logistic steps, or information on sensitivity analysis of the main parameters influencing the profitability of the management of pruning residues.

## The aim of the research

The aim of this work was to study the economic performance of the utilization of pruned biomass for energy purposes, considering the logistic chain from the harvesting stage at the orchard to the gate of the local heat-generation plant. The study was supported by a sensitivity analysis of the most important factors (orchard area, labour costs, transportation distance, bale price, quantity of pruned biomass) influencing the economic feasibility, as well as IRR and NPV values, based on a case study.

## Materials and methods

The data used in the analysis were obtained from an orchard enterprise located in Poland (Wieniawa municipality, Mazowieckie province, location: 51°22'56.6"N; 20°44'05.8"E). The logistic chain (and the boundary of the case study) of the use of pruned biomass for energy purposes on the local market is shown in Figure 1.

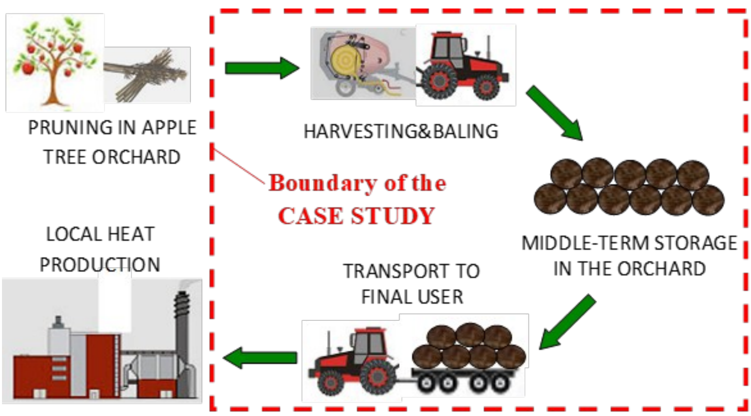


**Fig. 1. Scheme of the logistic chain in the PtE strategy**

The owner of the 100-hectare apple orchard prunes the trees every year in the winter–spring period and harvests the cut branches using a biomass baler and tractor (Table 1). The baler (Wolagri model R98) requires a power of ca. 38 kW to produce bales (diameter 1.2 m and width 1.0 m). The width of the machinery is less than 2.0 m, enabling its use in an orchard with rows spaced at a minimum of 2.5 m (more details are available at www.tonutti.it). The power of the PTO in the tractor is 46.3 kW, which is sufficient for performance of the harvesting process with the use of the Wolagri R98 baler (more details are available at www.kubota.com.au).

**Table 1. Basic technical data of the baler and tractor used PtE strategy**

| Feature | Biomass baler | Feature | Tractor |
|---|---|---|---|
| Model | Wolagri R98 | Model | KUBOTA M7040DHC |
| Bale diameter, cm | 120 | Engine | V3307-DI (4 cyl.) |
| Bale width, cm | 98 | Net Power, HP/kW | 68/50.7 |
| Pick-up width, cm | 130 or 190 disc end | Total displacement, cc | 3331 |
| Pressing chamber | fixed 32 crossbars | Max. travel speed, $km{\cdot}hr^{-1}$ | 31 |
| PTO shaft | PTO shaft homokinetic | PTO power, HP/kW | 62/46.3 |
| Tires supplied as standard | 11.5/80-15 | PTO type | Live-independent, hydraulic |
| Lubrication | optional | Tire size front/rear | 9.5x24/16.9x30 |
| Swiveling eyebolt Ø35 | standard | Overall length, mm | 3445 |
| Road signaling kit | standard | Overall height, mm | 2545 |
| Road homologation | standard | Overall width, mm | 1860 |
| Required power (kW/HP) | 38/50 | Turning radius, m | 3.6 |
| Transport width – mt | 1,71 | Lift capacity, kg | 1500 |
| Weight, kg | 1940 | Tractor weight, kg | 2440 |

The bales are collected and stored on-site in the orchard. The bales are stored along internal roads in the open air. They are stored for ca. 6-12 months, enabling the natural drying of the pruned bales and a decrease in the moisture content from ca. 45% to 15-20% [Velázquez-Marti et al. 2011]. Following mid--term storage in the orchard, the bales are delivered by the farmer (using his own trailer) to the final user (Fig. 2). The customer is a local high school, where heating boilers adapted for bale combustion are installed. Here the pruned biomass is converted into heat. The distance between the orchard and the final user is 6 km.

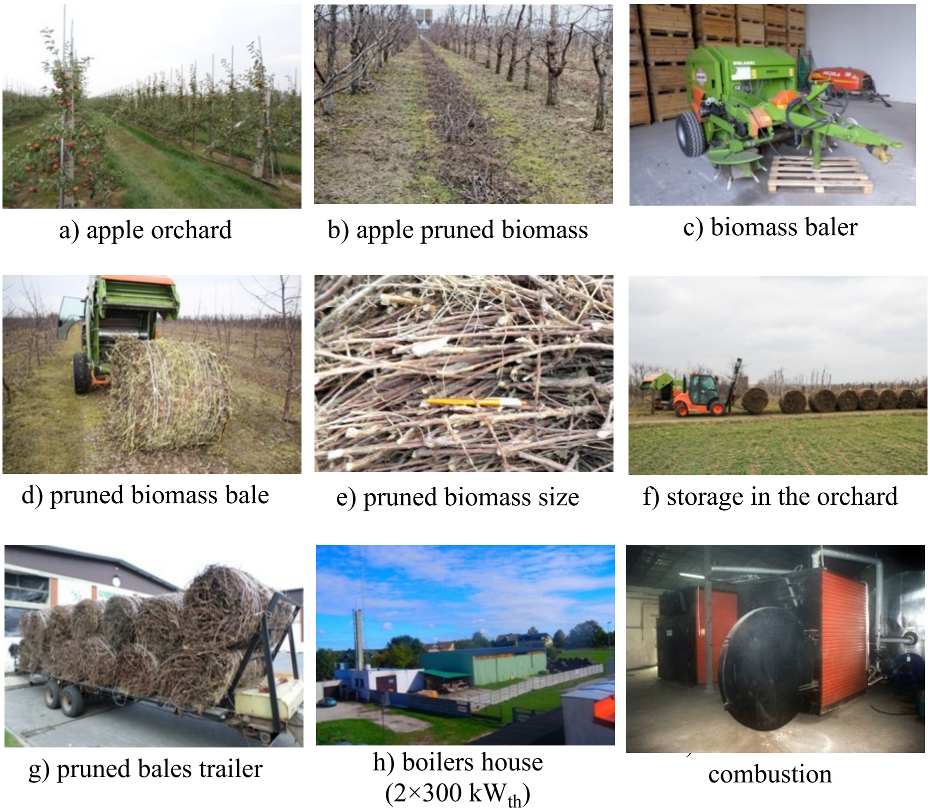


**Fig. 2. Pruning to Energy (PtE) strategy in the apple orchard (source: own materials, www:ogrodyinfo.pl, www.metalerg.pl)**

In order to perform an economic analysis of the utilization of pruned biomass from an apple orchard for energy purposes, the following assumptions were made:

– depreciation rate for agricultural machines (Act Dz.U. 1991 no. 80 item 350): 14%;
– discount rate: 5.0%;
– considered period of operations: 10 years.

The operation period of 10 years was considered reasonable based on recent studies on PtE value chains in Europe [EuroPruning 2016] and the service life of agricultural machines. The other techno-economic data required for the analysis are presented in Table 2. In the analysis the following costs are distinguished (Table 3):

– investment costs (disposable cash flow at the initial period);
– O&M costs (annual costs of operation and maintenance of the undertaking).

**Table 2. Characteristic data related to PtE strategy in the apple orchard**

| Orchard | Unit | Value |
|---|---|---|
| Area of the orchard | ha | 100 |
| Yearly pruning potential (moisture content ca. 45%) | $Mg \cdot ha^{-1}$ | 1.25 |
| Harvesting | | |
| Baler machinery capacity | $h \cdot bale^{-1}$ | 0.2 |
| Bales production | $bale \cdot ha^{-1}$ | 5 |
| Mass of the bale (during harvesting, moisture content ca. 45%) | $Mg \cdot bale^{-1}$ | 0.25 |
| Cost of tractor operation in the orchard during harvesting[1] | $€ \cdot h^{-1}$ | 10.0 |
| Cost of baler operation in the orchard during harvesting | $€ \cdot h^{-1}$ | 8.0 |
| Staff cost in the orchard during harvesting | $€ \cdot h^{-1}$ | 4.0 |
| Fuel consumption during baling | $dm^3 \cdot bale^{-1}$ | 1.0-1.25 |
| | $dm^3 \cdot Mg^{-1}$ | 4.0-5.0 |
| Transportation | | |
| Cost of internal transport and loading of bales in the orchard | $€ \cdot bale^{-1}$ | 0.5 |
| Transport capacity | $bale \cdot trans^{-1}$ | 30 |
| Transportation costs of bales to the consumer (full load, 30 bales) | $€ \cdot km^{-1}$ | 0.85 |
| Staff cost during transportation of bales to the consumer | $€ \cdot h^{-1}$ | 6.0 |
| Bales unloading time at consumer | $h \cdot trans^{-1}$ | 0.8 |
| Transportation distance (orchard-final consumer) | km | 6.0 |
| Bale | | |
| Bale diameter | m | 0.9-1.0 |
| Bale height | m | 1.2 |
| Mass of the bale (after 6 months of storage, moisture content ca. 15%) | $Mg \cdot bale^{-1}$ | 0.18 |
| Bale price at the final consumer gate | $€ \cdot bale^{-1}$ | 12.5 |
| | $€ \cdot tDM^{-1}$ | 90.9 |
| Mulching | | |
| Mulcher operation in the orchard | $€ \cdot h^{-1}$ | 4.4 |
| Mulching capacity | $h \cdot ha^{-1}$ | 0.9 |

[1]Similar value is available in the literature [Gaworski and Malinowski 2011, Niemiec, 2013].

The investment costs include a trailer and a baler (harvesting machinery), as these constitute additional equipment which is certainly required in the orchard to enable the farmer to pursue the PtE strategy. The purchase cost of the tractor is not included in the investment costs, because the farmer owned that item of machinery before beginning this new activity. Moreover, a tractor is used for many other activities in orchards (fruit transportation, spraying and fertilizing, water pump powering, etc.) which are outside the scope of this study. However, the tractor costs were determined based on the time of its operation in the orchard during the harvesting process. The cost of the tractor's operation was estimated to be 10 $€{\cdot}h^{-1}$ (Table 2).

The O&M costs included expenses such as the labour costs of employees engaged in harvesting, storage, loading and transportation to the final user. Here, costs related to internal transport and storage on-site (in the orchard) and the loading of bales on the trailer (for transportation to the final user) are accumulated and assumed to be 0.5 $€{\cdot}bale^{-1}$. In turn, the costs of transportation of bales from the orchard to the final user are assumed as 0.85 $€{\cdot}km^{-1}$ (www.pwik-konin.com.pl), which is an average market price for tractors or trucks performing this activity. The labour costs related to bale transportation and unloading are 6.0 $€{\cdot}h^{-1}$. Other costs used in the analysis are presented in Table 2.

**Table 3. Summary of expenditures and revenues related to PtE strategy in the apple orchard (100 ha)**

| Initial investment | Unit | Value |
|---|---|---|
| Baler (baling machinery) | € | 28500 |
| Trailer (used platform for bales transportation) | € | 1500 |
| Total: | € | 30000 |
| Operational and Maintenance costs | | |
| Baler (baling machinery) maintenance | $€{\cdot}year^{-1}$ | 500 |
| Trailer (platform for bales transportation) maintenance | $€{\cdot}year^{-1}$ | 50 |
| Baling of the pruned biomass | $€{\cdot}year^{-1}$ | 2200 |
| Internal transport and loading of bales in the orchards | $€{\cdot}year^{-1}$ | 250 |
| Transportation costs of bales to the consumer (6 km distance) | $€{\cdot}year^{-1}$ | 290 |
| Total: | $€{\cdot}year^{-1}$ | 3290 |
| Revenues | | |
| Bales selling | $€{\cdot}year^{-1}$ | 6250 |
| Avoided mulching costs | $€{\cdot}year^{-11}$ | 1650 |
| Total: | $€{\cdot}year^{-1}$ | 7900 |

It should be remarked that the baling of prunings also generates some avoided costs, namely mulching costs. Without the baling process the farmer would have to remove the cut branches from the orchard by applying other solutions, like mulching or pushing-out. These activities require additional costs (Table 2). As farmers mainly use mulching, in the analysis the cost of this operation is assumed to be 16.5 €·ha$^{-1}$ (including labour and machinery costs).

Additionally, Table 3 summarizes the expenditure and revenue related to the sale of the bales of pruned biomass.

Based on the costs generated during the harvesting and baling of the pruned biomass, logistics operations (loading, unloading, transportation to the final local customer) and the avoided costs (mulching), the financial consequences of this strategy were investigated.

The study used the Net Present Value (NPV) and Internal Rate of Return (IRR), which are among the most frequently used dynamic financial indicators [Berk et al. 2015]. In dynamic methods, the value of monetary flows depends on the time at which the transaction takes place. In the investigated Pruning-to--Energy strategy the flows include a one-off payment of investment costs, operating costs, avoided mulching costs, and future revenues from the sale of biomass for energy purposes. The present value of such cash flows is calculated by discounting future flows with a corresponding factor that depends on the interest rate adopted and the length of time between the payment and a reference time (in most cases, the beginning of the project) [Morvay and Gvozdenac 2008]. The equations used (eq. 1, 2, 3) were as follows [Brealey et al. 2009]:

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - I_0 \tag{1}$$

where: NPV is the Net Present Value, $CF_t$ is the net cash flow at time $t$, $r$ is the discount rate, $I_0$ is investment costs, $t$ is the time of the cash flow, and $T$ is the total number of periods (the duration of the calculated investment project in years).

The normal rule is to accept the investment if its NPV (in the time period assumed as satisfactory) is positive, and to reject it if the NPV is negative. Comparing several investments, the project with the highest positive NPV (in the same time period) is usually the most attractive.

A second indicator for the economic appraisal of investment projects is the IRR, which is based on the net present value method. The internal rate of return is calculated from the NPV equation on condition that there is such an interest rate for which the NPV is equal to zero:

$$\sum_{t=0}^{T} \frac{CF_t}{(1+IRR)^t} = 0 \tag{2}$$

Additionally, the Discounted Payback Period (DPP), as a simple capital budgeting method, is calculated to evaluate the time period needed for a project to bring in enough profits to recoup the initial investment. The formula for the DPP is as follows:

$$DPP = A + \frac{B}{C} \tag{3}$$

where:

- $A$ is the last period with a negative discounted cumulative cash flow;
- $B$ is the absolute value of discounted cumulative cash flow at the end of the period $A$;
- $C$ is the discounted cash flow during the period after $A$.

Finally, a sensitivity analysis was performed, as results of the economic appraisal of investment projects are uncertain because they are based on the future values of variables that are not known with certainty at present. The aim of a sensitivity analysis is to quantify the economic consequences of alternative values of crucial input parameters, including in this case: bale price, orchard area, quantity of pruned biomass, labour costs, and transportation distance.

## Results and discussion

Based on the assumptions and real data obtained during the measurements in the apple orchard (Tables 2 and 3), the NPV and the cash flows in the considered period of 10 years were determined (Fig. 3). The analysis showed that the NPV for a period of 10 years is €5644. The investment return period (when NPV = 0) is 8.04 years (Fig. 4), and the IRR is 8.71%. Considering that the PtE strategy represents an investment in the energy market, the result achieved can be classified as acceptable and satisfactory.

It should be remarked that the positive result obtained for the described investment in this apple orchard depends on many parameters, including quantity of pruned biomass, price of the final product, labour costs, orchard size, storage costs, distance to the final user, orchard management, machinery and maintenance costs, etc. [Spinelli and Picchi 2010; Velázquez-Martí et al. 2012; Bosona et al. 2019; Dyjakon 2019]. Therefore, a sensitivity analysis of selected parameters was carried out (Fig. 4), applying changes to the values of important factors in a range from –25% to +30%. The discounted payback period was calculated for the respective changed values. The results revealed that the major influence on the return on the investment comes from the selling price of the biomass (the bale price in this case). If the reference price is 12.5 €·bale$^{-1}$ (90.9 €·tDM$^{-1}$) then the DPP indicator varies from 13.4 years (if the bale price falls by 25%) to 5.5 years (if the bale price increases by 25%). The undertaking is thus fairly sensitive to variation in the biomass price. To minimize the prospective negative effect, middle- and long-term contracts for biomass delivery should be prioritized.

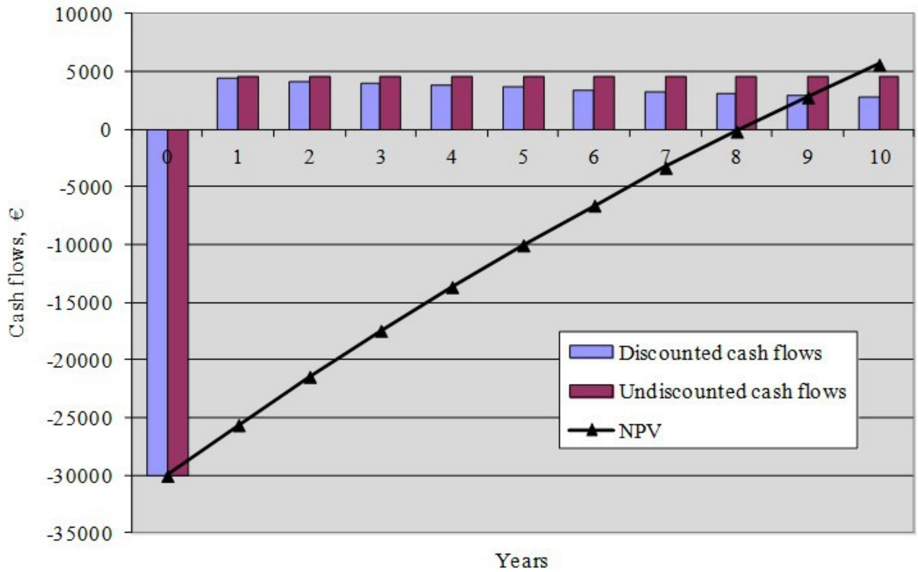


**Fig. 3. Undiscounted and discounted cash flows of the PtE strategy for a 100 ha of the apple orchard**

Other parameters influencing the profitability of the PtE strategy include the quantity of pruned biomass harvested from one hectare of the orchard. Research performed in different orchards and vineyards [Magagnotti et al. 2013] revealed that pruning harvesting costs (and therefore DPP) increased with the extraction distance and decreased with residue concentration. Assuming this concentration as 1.25 $Mg \cdot ha^{-1}$, the DPP is 8.04 years. A reduction of the concentration by 25% causes the DPP to increase to 10.3 years (over two years longer). A 25% increase of the amount of pruned biomass leads to a shortening of the DPP to just 5.5 years. Although this factor seems to be significant, in practice it is not as important, because the quantity of prunings in an apple orchard (especially in an intensive one) is stable over several years of cultivation, or may slightly increase (due to growth of the tree mass). If the initial pruning concentration is satisfactory (at the beginning of the PtE strategy), the risk of a decrease in pruning availability is marginal.

In turn, the smallest influence on the DPP comes from labour costs. Increasing the labour costs in the harvesting process by 25% causes a change in the DPP by less than 0.02 of a year (the DPP increases from 8.04 to 8.05 years). This can be explained by the fact that pruned biomass harvesting does not require many workers. Therefore, a potential increase in labour costs does not play a very important role in the total calculation of the DPP. Hence, small variations in employee wage costs are not crucial for the PtE strategy.

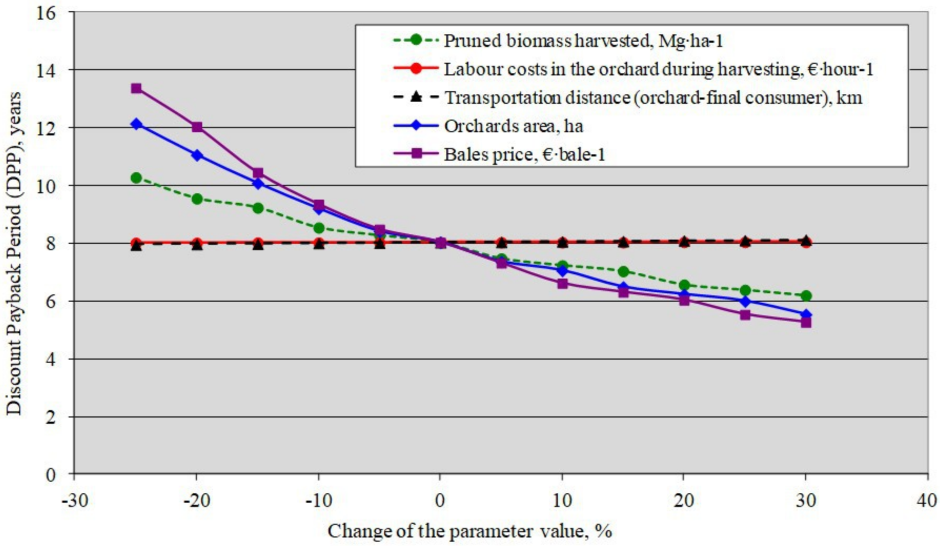


**Fig. 4. Sensitivity analysis of the main parameters influencing PtE strategy**

However, the orchard size is very important in this respect, because it determines the harvesting (baling) machinery load time. If the baling machinery is not used for long enough during the pruning season, then the income from the sale of biomass is not sufficient to cover the expenses related to the purchase of the machinery. Hence, there is a minimum orchard size that needs to be served by the baling machinery to maintain adequate profitability. In the case considered, the area served by the machinery is 100 ha. A decrease in the orchard area by 25% increases the DPP by ca. 4 years, whereas an increase in the orchard area by 25% shortens the DPP by 2.0 years. This means that a decrease in the accessible area in the orchard would have a more significant impact than an increase. In this regard, it is very important to determine the minimum orchard size for which the use of the specialized machinery is economically justified. Therefore, for deeper analysis, the harvested orchard area was increased from 100 hectares up to 300 hectares and decreased down to 55 hectares. More detailed calculations showed (Fig. 5) that with an orchard area below 80-85 ha the DPP increases significantly, and with a further decrease in the orchard area the DPP continues to increase (for instance, reaching 21.3 years for an orchard size of 55 ha). This indicates that when the orchard area is reduced by almost half (from 100 ha to 55 ha), the DPP becomes more than 2.5 times as long. On the other hand, a doubling of the orchard area (from 100 ha to 200 ha) shortens the DPP from 8.04 years to 3.3 years. This very positive effect on the DPP is caused by the more intensive use of the harvesting machine in the orchard and higher income from the sale of bales. As a consequence, the investment cost related to the baler (harvesting machine) is returned faster. However, this trend is subject to some limitations for larger orchard areas. A further increase of the orchard area still brings some benefits, but they are not so substantial. When the area is increased further from 200 ha to 300 ha, the DPP falls from 3.34 years to 2.15 years. For an area of 400 ha, the DPP is reduced to 1.63 years. It appears that above ca. 200 ha the size of the orchard no longer has a significant influence on the DPP. Similar results, concerning different machinery and technologies, have been obtained in another study [Fiala and Bacenetti 2012]. For large orchard areas, the fall in the cost of harvesting operations flattens out [Spinelli et al. 2010]. For very large orchard areas (above 500-1000 ha), the purchase of additional harvesting machinery might be necessary, not only to ensure the timely completion of the work in the orchard, but also to maintain operational capacity in case of failure of one machine.

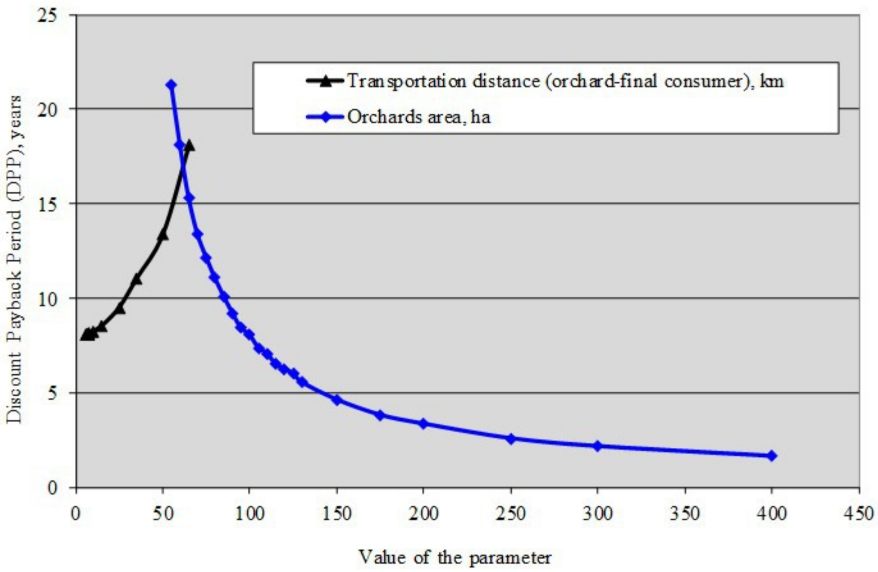


**Fig. 5. Influence of orchards size and transportation distance to final consumer on DPP**

If the transportation distance is short (local range), the costs of pruned biomass delivery are not significant. The change in the DPP is less than 0.02 years in both directions on the horizontal axis of Figure 4. The small impact of the transportation distance on the DPP results from the fact that in the case considered the final customer is located only 6 km from the orchard. To obtain more information about the effect of the distance to the final user on the DPP, additional calculations were performed assuming transport distances up to 50 km and more (Fig. 5).

The results indicated that transportation of the pruned biomass over longer distances significantly affects the profitability of the undertaking. When the transportation distance of the bales is up to 25 km, the DPP remains below 10 years. However, for longer distances the DPP starts to increase faster. For a distance of 35 km the DPP is ca. 11.0 years, whereas for 50 km the DPP is ca. 13.3 years. For a distance of 65 km, the DPP is over 18 years, making the PtE strategy financially unacceptable. The importance of the distance between the farm and final user for the economic balance of the PtE strategy has also been indicated in other works [Toscano et al. 2018; Bosona et al. 2019]. Moreover, long-distance transport reduces the value of the activity in terms of local resource utilization in the local market, and affects regional sustainable development. Also, environmental aspects start to play an important role when transport distances become longer.

## Conclusions

The biomass from orchard pruning is regarded as wooden residue that needs to be removed from the plantation. On the other hand, as a lignocellulosic material, it is a valuable renewable fuel for heat production. In the management of apple orchards in Poland, farmers may reduce costs and generate income by avoiding burning or mulching pruned biomass and instead selling it to local heat plants. However, to adopt the PtE strategy, many factors and dependences related to the logistic chain must be adjusted to ensure revenue for the farmer.

The main objective of this paper was to verify the importance and the influence on the discounted payback time of such factors as quantity of prunings in the apple orchard, orchard area, final biomass price, labour costs and transportation distance. To achieve this goal, a case study was made of a 100 ha apple orchard. Investments and operating costs were defined and used to calculate the NPV, IRR and DPP indices. Finally, using sensitivity analysis, the most significant parameters for the PtE strategy were identified and discussed.

The case study analysed in this paper allowed us to draw some general conclusions:

– if the PtE strategy is planned properly, it can generate additional profits for the farmer;
– the selling price of the pruned bales is the most important parameter influencing the profitability of the use of wooden residues from an apple orchard for energy purposes;
– the size of the apple orchard served by the baling machinery and the distance from the heat plant are crucial for maintaining a positive NPV in a period up to 10 years;

– for smaller orchards the baling machine is too expensive, and the profits from the sale of biomass are not sufficient to cover its costs;
– the distance of transportation of the pruned bales should not exceed ca. 25 km.

The case study proves that the PtE strategy might be a very good option for farmers to increase their income and to propagate the use of a local renewable energy source in small or middle-size boilers for local heat production. On the other hand, it also shows that a farmer should research the local market before taking a decision, to ensure that there is demand for pruned biomass residues in the close surroundings. Similar case studies on PtE strategies should be made to enable farmers to improve their economic performance and to promote sustainable development in regions with orchards producing adequate pruning residues.

## List of abbreviations

| | | | |
|---|---|---|---|
| *EU* | European Union | NPV | Net Present Value |
| PtE | Pruning-to-Energy | IRR | Internal Rate of Return |
| RES | Renewable Energy Sources | O&M | Operation and Maintenance |
| LHV | Lower Heating Value | CF | Cash Flow |
| PTO | Power Take Off | DPP | Discounted Payback Period |

## References

**Act Dz.U. 1991 no. 80 item 350** [1991]: Appendix 1 to the Act of 26 July 1991 on income tax (in Polish)

**Alfonso D., Perpina C., Perez-Navarro A., Penalvo E., Vargas C., Cardenas R. [**2009]: Methodology for optimization of distributed biomass resources evaluation, management and final energy use. Biomass and Bioenergy 33: 1070-1079

**Asztemborski B., Wnuk R.** [2015]: Poland's promising market segments for heating with solid biomass (>100 kW). Report. Horizon 2020 Coordination and Support Action number 646495: Bioenergy for Business "Uptake of Solid Bioenergy in European Commercial Sectors", The Polish National Energy Conservation Agency (KAPE), Warsaw, July 2015

**Berk J., DeMarzo P., Stangeland D.** [2015]: Corporate Finance (3rd Canadian ed.). Toronto: Pearson Canada

**Bertrand V., Dequiedt B., Le Cadre E.** [2014]: Biomass for electricity in the EU-27: Potential demand, $CO_2$ abatements and breakeven prices for co-firing. Energy Policy 73: 631-644

**Brealey R., Myers S., Marcus A., Maynes E., Mitra D.** [2009]: Fundamentals of Corporate Finance, McGraw-Hill Ryerson

**Bosona T., Gebresenbet G., Dyjakon A.** [2019]: Implementing life cycle cost analysis methodology for evaluating agricultural pruning-to-energy initiatives, Bioresource Technology Reports 6 (June): 54-62

**Bosona T., Gebresenbet G., Garcia D.** [2016]: Logistics Performances of Agricultural Prunings' Supply Chain; 24th European Biomass Conference and Exhibition, EUBCE 2016: 1BV.4.64, June 6-9, 2016, Amsterdam, The Netherlands

**Carvalho L., Wopienka E., Pointner C., Lundgren J., Verma V.K., Haslinger W., Schmidl C.** [2013]: Performance of a pellet boiler fired with agricultural fuels. Applied Energy 104, 286-296

**Dyjakon A.** [2019]: The influence of apple orchard management on energy performance and pruned biomass harvesting for energetic applications. Energies 12: 632

**Dyjakon A., Den Boer J., Bukowski P., Adamczyk F., Frąckowiak P.** [2016]: Wooden biomass potential from apple orchards in Poland, Drewno (Wood) 59 [198]: 73-86

**EuroPruning** [2016]: Economic evaluation of biomass supply chain. Working document of EuroPruning project – new logistics chain on biomass from pruning. Available from: http://www.europruning.eu/

**EUROSTAT** [2015]: Sustainable development in the European Union. 2015 monitoring report of the EU Sustainable Development Strategy. Luxembourg, Publications Office of the European Union. Available from: http://ec.europa.eu/eurostat/documents/3217494/6975281/KS-GT-15-001-EN-N.pdf. accessed: 29.12.2016

**EUROSTAT** [2016]: Regional statistics by NUTs classification of Eurostat. Data on Regional agriculture statistics. "Structure of agricultural holdings" dataset. Data for year 2010. Available from: http://ec.europa.eu/eurostat/web/regions/data/database. Obtained in February 2016

**Fiala M., Bacenetti J.** [2012]: Economic, energetic and environmental impact in short rotation coppice harvesting operations. Biomass and Bioenergy 42: 107-113.

**Frąckowiak P., Adamczyk F., Wąchalski G., Szaroleta M., Dyjakon A., Pari L., Suardi A.** [2016]: A prototype machine for harvesting and baling of pruning residues in orchards: first test on apple orchard (MALUS MILL.) in Poland. Journal of Research and Applications in Agricultural Engineering 61 [3]: 88-93

**Gaworski M., Malinowski K.** [2011]: Analiza transformacji gospodarstwa ogrodniczego z uwzględnieniem aspektów technicznych (Analysis of horticultural farm transformation including some technical aspects). Agricultural Engineering 9 [134]: 41-48

**GUS (Central Statistical Office)** [2016]: Użytkowanie gruntów i powierzchnia zasiewów (Land use and sown area). Reports, Warsaw [accessed: 15.12.2016]. Available from: www.stat.gov.pl

**Magagnotti N., Pari L., Picchi G., Spinelli R.** [2013]: Technology alternatives for tapping the pruning residue resource. Biores. Technol. 128: 697-702

**Morvay Z., Gvozdenac D.** [2008]: Applied Industrial Energy and Environmental Management, October 2008, Wiley-IEEE Press (ISBN: 978-0-470-69742-9)

**Niemiec A.** [2013]: Koszty eksploatacji ciągników rolniczych (The costs of operation of farm tractors), Lower Silesian Agricultural Advisory Centre, Available from: www.dodr.pl

**Rabcewicz J., Białkowski P., Konopacki P.** [2010]. Assessment of amount of wood from pruned apple orchards as a source of renewable energy. Journal of Fruit and Ornamental Plant Research 18(2): 249-254.

**Rentizelas A.A., Tolis A.J., Tatsiopoulos I.P.** [2009]: Logistics issues of biomass: The storage problem and the multi-biomass supply chain. Renew Sustain Energy Rev. 13: 887-894

**Romański L., Dyjakon A., Adamczyk F., Frąckowiak P.** [2014]: Problems with deriving the fruit tree pruned biomass for energy use. Agricultural Engineering 151 [3]: 157-167

**Spinelli R., Picchi G.** [2010]: Industrial harvesting of olive tree pruning residue for energy biomass. Biores. Technol. 101: 730-735

**Spinelli R., Magagnotti N., Nati C.** [2010]: Harvesting vineyard pruning residues for energy use. Biosystems Engineering 105: 316-322

**Toscano G., Alfano V., Scarfone A., Pari L.** [2018]: Pelleting vineyard pruning at low cost with a mobile technology, Energies 11: 2477

**Velázquez-Marti B., Fernández-Gonzáles E., Lopez-Cortes I., Salazar-Hernandez D.M.** [2011]: Quantification of the residual biomass obtained from pruning of vineyards in Mediterranean area. Biomass Bioenergy 35: 3453-3464.

**Velázquez-Martí B., Fernández-González E., Callejón-Ferre A.J., Estornell-Cremades J.** [2012]: Mechanized methods for harvesting residual biomass from Mediterranean fruit tree cultivations. Sci. Agric. 69: 180-188

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