Technical Options of Pruned Biomass Harvesting in the Apple Orchards Applying Baling Technology and Its Conversion to Energy

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Abstract The reduction of fossil fuels usage and increase of local agricultural and forest residues for energy purposes belong to the main drivers to face with a climate change in a sustainable and environmentally friendly way. One of the alternative sources of wooden residues from agriculture is biomass generated during a regular fruit trees pruning. In Poland, there is a significant potential of pruned biomass from apple orchards that might be used to produce energy. In the paper the options of pruned biomass harvesting applying baling technology are presented. Next, the possibilities of the bales handling and their optional further treatment to produce energy are described. It was shown that depending on the local market requirements, the energetic use of pruning residues is feasible and may parallel lead to the CO_2 emission reduction to the atmosphere.

Keywords Pruning · Apple orchard · Biomass harvesting · Baling technology · Energy

1 Introduction

Biomass is a very important source of energy having a significant contribution to achieve the European target expected in the climate and energy package by 2020 [1]. To increase further their share on the energy market and strengthen the European strategy on bio-economy, it is necessary to use more and more of agriculture by-products [2]. In apple orchards there are many options to gain the biomass residues suitable for energy production (see Fig. 1).

One of the interesting and valuable resources of waste biomass is pruning. Prunings are woody residues composed mainly by small branches and twigs produced during the regular management activity related to the care of agricultural crops such

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Fig. 1 Biomass sources in the apple orchard

as orchards, vineyards or olive groves. One of the fruit orchards having potential to generate energy from wooden residues are apple orchards. To maintain high fruits quality and productivity, apple orchards require proper treatment, including branches pruning in the winter-spring period [3]. In case of significant deterioration of the apples production (after 20–30 years in average), the old trees are removed and to new one are planted. As a result, the pruning residues from apple orchards (see Fig. 2) are characterized by a regular yearly production of lower amounts of biomass per hectare (up to few Mg ha^{-1}, in average 3.5 Mg ha^{-1}) [4], and uprooting residues obtained at the end of the commercial life of the given plantation (even up to 100 Mg ha^{-1} or more). Both residues must be disposed of, but different possible strategies might be applied leading to different final results, profits or costs.

Taking into account the size distribution area of the apple orchards in Europe, harvesting losses of branches and high heating value of wooden material the total energetic potentials from yearly pruning operations are: 29.11 PJ/year for theoretical, 22.50 PJ/year for technical and 18.63 PJ/year for economic. According to Poland, which possess the highest shares of the apple orchards in Europe, these values are 9.3 PJ/year, 7.4 PJ/year and 5.9 PJ/year, respectively [3].

In relation to the year by year trees pruning in the apple orchards, the following options might be recognized (see Fig. 3):

- pruned biomass mulching on the inter-row area,
- pruned biomass removal from the inter-row area and open-air combustion on site,
- pruned biomass harvesting and use for other purposes (i.e. energy production).

After pruning, ligneous residues are generally left spread all over the ground in the orchard. Processing in the orchard requires to carry out their elimination. If they are not removed, they become an obstacle for the other cultivation operations

Fig. 2 Options of pruned biomass treatment in the apple orchards

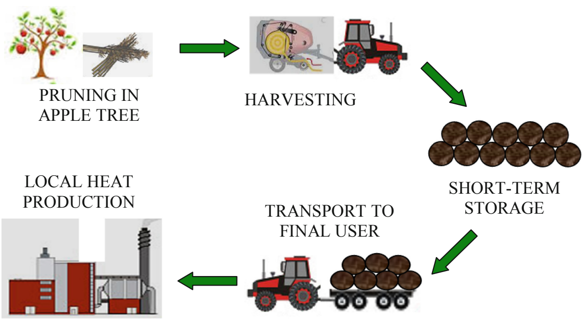

Fig. 3 The use of pruned biomass for energetic purposes [11]

related to fruit (apples) production. In case of mulching and on-site burning, both options are costly and do not bring any financial benefits for a farmer. Leaving mulched residues in the soil contribute to enhance the organic matter content, but on the other hand it does not solve a problem with increasingly aggressive pests [5]. Removal of the pruned branches is usually carried out with tractors provided with rakes or similar devices for dragging (picking-up) the branches along the rows to dispose burn them on site (at the end of the orchards headland). However, open-air combustion is forbidden in most European countries due to the fire hazards. Therefore, the harvesting of the wooden residues in the apple orchard and their use for energetic purposes (PtE – Pruning to Energy) seems to be more efficient and reasonable. There are three general options the branches can be harvested:

– manual collection,
– mechanical collection combined with chipping,
– mechanical collection combined with compaction (baling).

Manual collection of cut branches is performed very rarely as it is time consuming. Moreover, the loose form and a very low bulk density of manually harvested biomass disqualifies its combustion in the boilers.

Mechanical collection and chipping is an effective procedure [6, 7], but the harvested wet biomass residues requires later more strict storage conditions (i.e. forced drying, under a roof storage or periodic pile overturning) to prevent material properties deterioration or rotting. As a result, this technology is attractive and good in terms of chips combustion in the energetic units, but the harvesting process is more expensive and demands more direct energy input (i.e. fuel consumption) [8] than baling technology [9].

The alternative solution is mechanical collection combined with baling. The procedure is cheaper and requires less energy input in comparison to chipping [9, 10]. Additionally, the natural open air drying of bales, preventing material decomposition during storage, might be applied. However, some inconvenience is the necessity of having dedicated boilers for bales combustion to maintain the whole logistics chain simple in realization.

The aim of the paper is (i) the review of the options of pruned biomass harvesting in the apple orchards applying baling technology and (ii) the review of the possibilities of pruned biomass bales conversion to energy.

2 The Pruning to Energy Strategy

The concept of pruned biomass baling system, which is focused on PtE strategy with ecological and economic footprint (see Fig. 4), is simple [11]. The idea is to harvest the pruning residues in the orchard in a single pass and with one operator

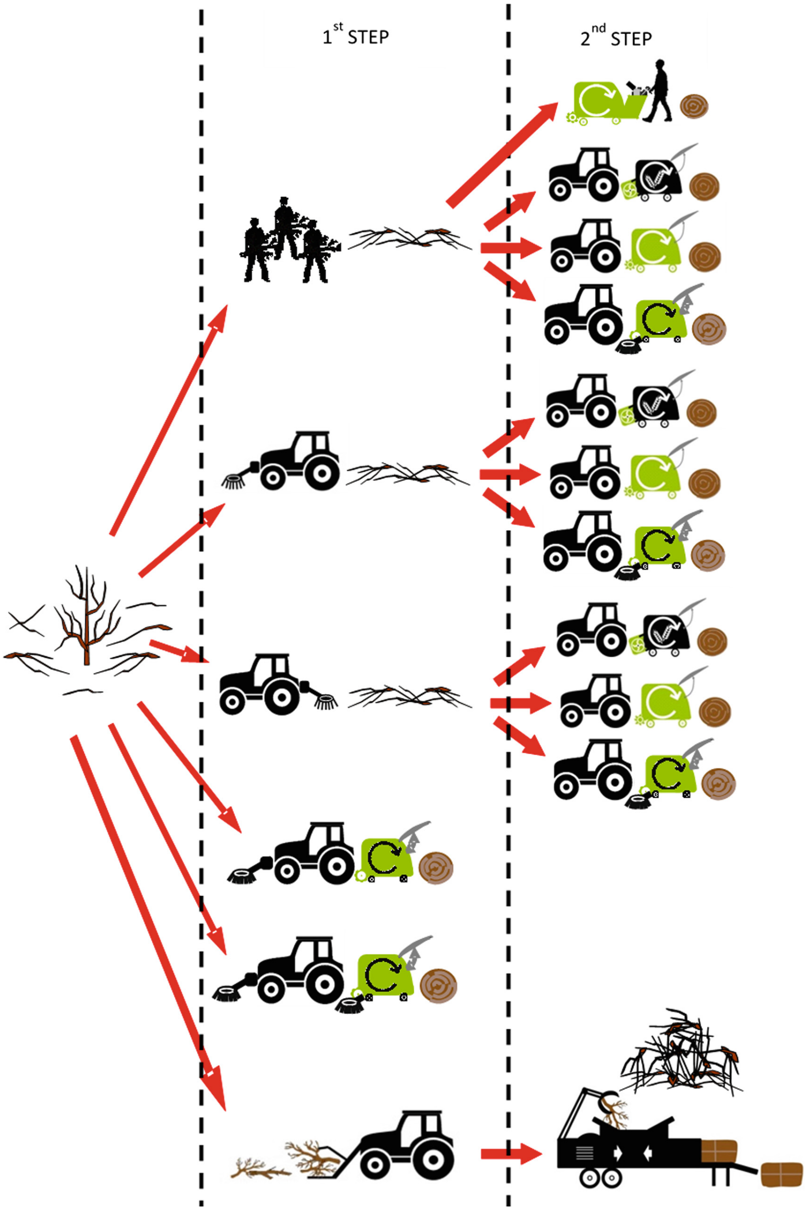

Fig. 4 Main technological options of pruned biomass baling in the apple orchard

only. The baler picks up and compacts pruning residues into dense round bale. After the harvest the produced bales are collected and stored on site (or delivered to the plant). It is important that the pruning bales will not deteriorate during storage over a long period (unlike a pile of woodchips that are rotting), even though they are harvested in very wet conditions. During the next few weeks the natural drying process takes place without a risk of spontaneous combustion. It arises from the fact, that although the wet pruned residues are compacted, there is still enough space for the air flow between the branches under open-air storage. As a result, the moisture content in the raw material decreases from 45–55% to 15–20% increasing the lower heating value [12, 13]. Finally, the bales are ready to be transported to the final consumer.

Having a suitable biomass boiler the bales might be directly combusted to produce heat and/or electricity. It should be marked that the shape and density of bales allow a better cost efficient transportation from the field to the power plant with conventional equipment (transportation platform, open trailer, etc.).

3 Pruning Harvesting Options Applying Baling Technology

Many adopted and dedicated machineries have been developed to scrape, pick-up, harvest and convert the pruning residues into valuable product in the form of bales [14] that might be stored and used later by final consumer for heating. Therefore, many options are available on the market which the farmer can choose and apply in the apple orchard (see Fig. 5).

Depending on the advancement of the technology the pruned biomass in the apple orchard might be harvested in one or two-stage processes. Currently, the most common approach is two-stage technology [14, 15]. Because of in the majority of the cases, after the pruning, the cut branches and shoots lie scattered around the apple trees, in the first stage, they must be gathered in the middle of the interrow. This operation might be done by the workers during the pruning of the trees.

(a) in front of the tractor (b) in rear of the tractor (c) in front of the baler

Fig. 5 Options for windrowers attachment to improve pruned biomass harvesting process

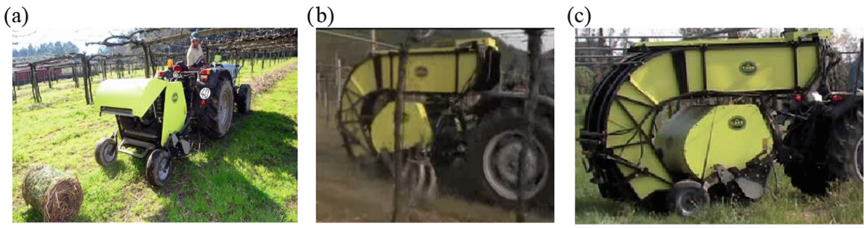

Fig. 6 Small baler for pruned biomass baling strategy (*Source* www.caebinternational.it): **a** small baler without additional equipment, **b** small baler with windrowers and temporary storage unit of bales, **c** small baler with temporary storage unit of bales

Although it requires more time, it increases harvesting efficiency (there are lower harvesting losses). However, to save time and facilitate the harvesting process, the device called a sweeper or windrower are in use [16]. Usually, they are attached to the tractor (in front or in rear) as well as to the baling machinery (see Fig. 6). As a result, the machine simultaneously removes the branches from both sides of the interrows and sweeps them to the middle part. In more developed models, thanks to the adjustable arms, it is possible to regulate the distance between the sweeping rotors and the range of the operation [16].

The windrowers are made of flexible and highly resistant plastic bars or rubber. The rotational speed of rotors may be smoothly adjusted with the use of hydraulic drives, depending on the needs and conditions. The examples of the selected machineries in operation are shown in Fig. 6.

The second stage of this process is an appropriate baling of the pruned biomass arranged in the middle of the interrows. For this purpose the professional machineries for pressing the pruned biomass, called balers, are used [17, 18]. The pruned residues are collected from the interrows with the use of a pick-up system and then fed into the baling chamber, where the rubber belts, rolls, or a combination of rolls and chains, roll up the pruned residues into cylindrical-shaped bales. At the end of the process the bale is wrapped with a plastic or organic string (or net) to avoid bale destruction and maintain the proper shape during the storage or transportation period [16]. These machineries are mounted on the back of the tractor and they are supplied with power from PTO (Power Take-Off). In Figs. 7 and 8 some examples of the balers with optional equipment are shown.

It should be added that on the market there is also available a pressing (baling) machinery producing the rectangular bales (Fig. 9), but it is not so popular, like a round baler.

In case of compaction, there are two forms possible to be produced (see Fig. 10):

– rectangular bales (very rarely),
– round bales.

(a) big baler with windrowers (b) big baler without additional equipment

Fig. 7 Big baler for pruned biomass baling strategy [19]

(a) (b) (c)

Fig. 8 Baler producing rectangular bales (*Source* www.lerdaagri.com)

(a) rectangular bale (b) round bale (d) temporary pruned bales storage

Fig. 9 Compacted pruned biomass bales in the apple orchards

The size of rectangular bales produced from pruned biomass in the orchards is 32 × 42 cm or 36 × 46 cm (www.lerdaagri.com), whereas diameter of the round bales might vary from 30–40 cm up to 120 cm. The length of the bales is ca. 60 cm (small bales) and ca. 100–120 cm (big bales), respectively [9, 20, 21].

It should be marked that in practice about the choice of the baling strategy and the size of the produced bales decide many parameters, like [22, 23]: orchards size and characteristics, economic pruning potential, local market requirements and demand for biomass, biomass price etc.

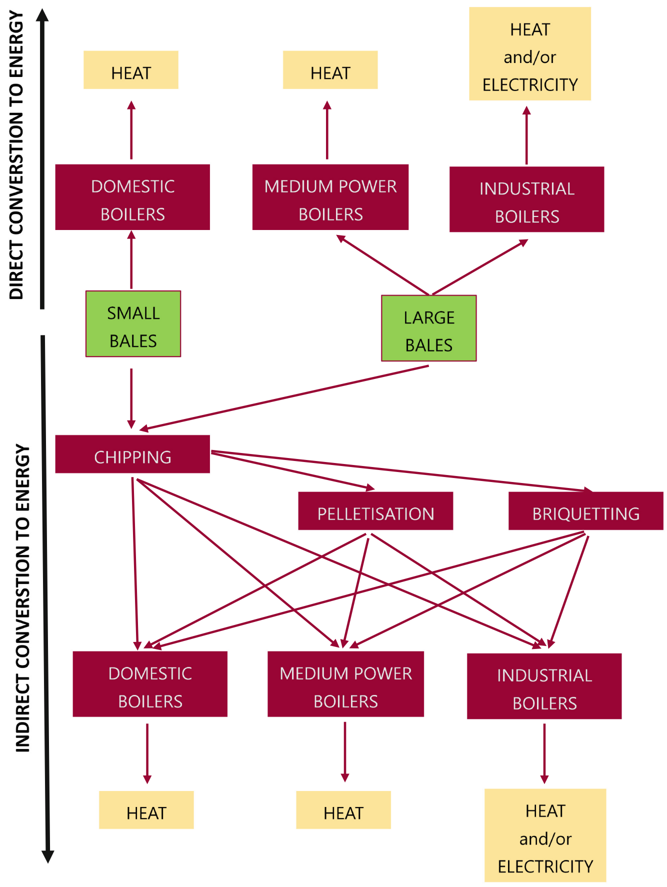

Fig. 10 Pruned biomass conversion options to energy

4 Conversion Options of Pruned Biomass Bales to Energy

The pruned bales from apple orchards are a good wooden material to be used for energetic purposes. It is characterized by heating value in the range of 17–19 MJ/kg [4, 24] which is similar to other wastes coming from agricultural and forestry sector [25]. The conversion of chemical energy contained in biomass bales into useful energy might be realized throughout their direct or indirect combustion in the boiler (see Fig. 11).

In case of direct pruned bales burning to generate heat and/or electricity the dedicated boilers with an appropriate volume of the combustion chamber are required. The size of the boiler decides about the thermal capacity and the feeding frequency. As a consequence, the large bales are designed for institutional heating systems or commercial central heat and power plants (see Fig. 12), whereas the

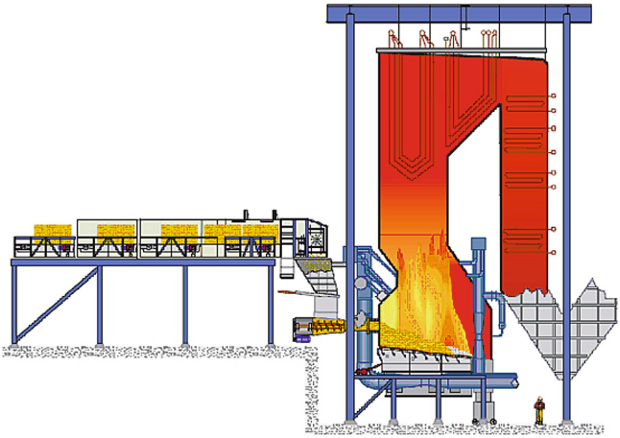

Fig. 11 Commercial heat and power plant for bales combustion (www.volund.dk)

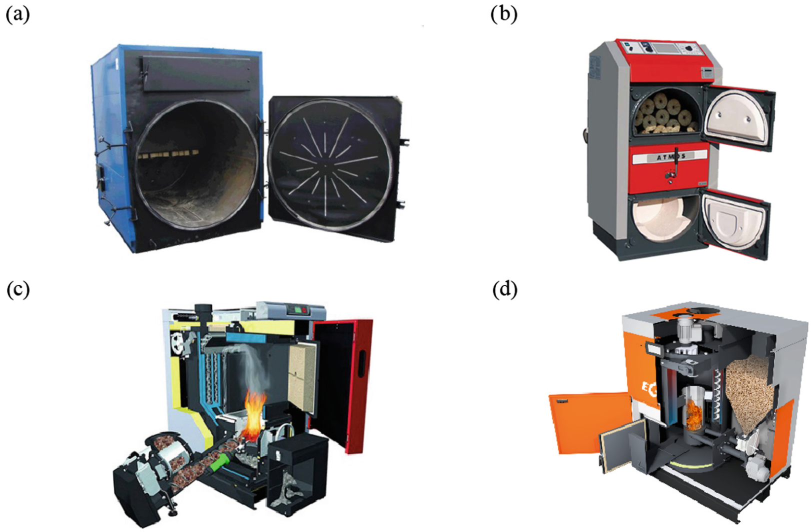

Fig. 12 Small power boilers assigned to the combustion of pruned biomass in the form of: **a** bales (www.tilgner.pl), **b** briquettes (www.atmos.eu), **c** wood chips (www.valeenergy.co.uk), **d** pellets (www.ekogren.pl)

small bales are suggested for smaller and individual heating units assigned mainly to households (see Fig. 12a).

If direct combustion of bales is not possible, the indirect method have to be applied. The bales are transformed to other form of solid fuel. Depending on the requirements, they might be converted to wood chips, pellets or briquettes. Then, the obtained solid biofuels are suitable for small scale (see Fig. 12b–d) as well as for

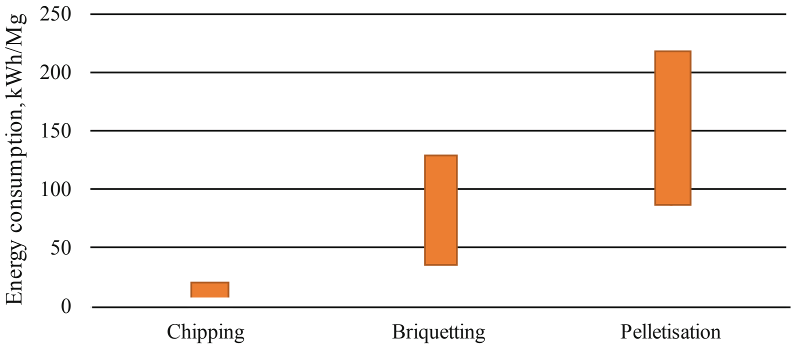

Fig. 13 Approximate energy demand for a process of pruned bales conversion [26–33]

commercial scale utilization. The main disadvantages of indirect direction of bales combustion are higher costs of the process caused by the additional energy input to comminute the bales and produce wood chips, pellets or briquettes. The approximated values of the energy demand required for chipping, pelletisation and briquetting processes are shown in Fig. 13.

Besides the energetic benefits, there is also an environmental aspect that is of added value to this logistics chain. The usage of pruned biomass for energetic purposes contributes also to the reduction of CO_2 emission. The CO_2 emission index from bituminous coal combustion (as the typical conventional fuel) is 94.7 kg/GJ [34] or 357 kg/MWh [35]. Assuming the combustion efficiency in the heating boilers (0.92) and the lower heating value for pruned biomass 18.0 GJ/Mg), the avoided carbon dioxide emission amounts to more than 1500 kg per tonne of wooden by-product material.

5 Conclusions

The removal of pruned biomass in the apple orchards is obligatory. Across the various options, the harvesting of the biomass applying baling technology seems to be the most effective, especially in terms of energetic input. Depending on the technical facilities and financial possibilities, the harvesting process might be realized using simple or sophisticated machinery. The bales collected in the apple orchard are after several-month storage period ready for combustion in the heating unit having also an positive environmental impact in reduction of carbon dioxide emission. However, it is conditioned by the possibility of whole bale combustion in the boiler. Otherwise, additional steps of biomass conversion will have to be applied to adopt the biomass form to other boiler requirements which results on significant energy input and make a whole logistic chain more complex.

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