



# Utilization of post-production waste from fruit processing for energetic purposes: analysis of Polish potential and case study

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## Abstract

There is no doubt that waste products from fruit and vegetable processing are difficult to manage. In that context, partial substitution of conventional energy substrates by industrial waste is an alternative, as it helps to utilize residues and at the same time to reduce the fixed cost of running business. The aim of the article is to analyse the possibilities of using fruit processing wastes for energy purposes in Poland. The assessment on a country scale was based on the data of the Central Statistical Office. Analogical analysis was based on the data collected from selected production plant. The obtained results show that the fruit processing waste can be successfully utilized for energy purposes. At the same time, problems of organizational nature should not be overlooked, as they can significantly decrease that potential. Although the amount of energy obtained from this source is basically negligible in the Polish energy balance, the environmental factor should not be ignored also. Therefore, the utilization of waste products from fruit processing should be a topic of interest, as it works in two ways, i.e., through reducing the amount of waste and increasing production of renewable energy.

**Keywords** Utilization of biomass · Post-production waste · Fruit processing · Renewable energy production

## Introduction

Waste products from fruit and vegetable processing are difficult to manage. Management should be understood as its storage and especially disposal [1–3]. The main problem here is the variety of waste depends on the production in a particular region and on different specifications of substrates [4]. In case of production plants that deal with many different species of fruits and vegetables, the quantity and variety of waste can be very rich. There are many ideas leading to minimizing the amount of waste products. The most popular is using them as a fuel in a solid form [5, 6], or in the form of pellet [7], biogas [8, 9] or biofuel [10, 11].

Other ideas includes livestock feed [12, 13] and production of other products, like dietary fibre [5, 11], alcohols (usually ethanol [14] or butanol [15]) and many others [5, 11, 12, 16]. It should be added here that organizational aspect in the branch of industry in question is very hard. Poor stability of fruits and vegetables in storage, unevenness of yield resulting from many unpredictable factors (e.g. weather or pests), a large number of species and varieties of fruits and vegetables of different processing usefulness and many processing directions. Each of these factors affects the processing and utilization of waste from fruit and vegetable processing. Especially the first two of them can be a problem in terms of predicting the amount of waste that will be available during a given period, as they cannot be truly estimated considering unpredictability of phenomena such as droughts, floods or crop plagues.

The use of post-production waste for energetic purposes allows not only for the minimization of the quantity of waste, but can also reduce the overall cost of running business. Most of the above referenced papers concentrate on the ideas of waste utilization or obtained product specification. There is a lack of works directly relating to particular market situation and detecting the true potential of analysed product obtained from waste or specific case studies. That is why

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the aim of this article is to investigate the possibilities of using waste from a fruit and vegetable processing for energy purposes based on a case study. We analysed the chosen production plant data and placed them on a wider background, i.e., referring to the Polish regional specificity.

## Materials and methods

Our work is based on two sources. The first one is the Central Statistical Office of Poland (CSO) [17] with the Statistical Yearbook of Agriculture 2016 [18], covering the year 2016 and containing data of up to 2005, being the main source of information. The second source of data is the investigated production plant, i.e., Fruit and Vegetable Processing Plant “Lubawa”. The company is located in the Warmian-Masurian Voivodship, which is a province in north-eastern Poland. It is classified as a medium-sized enterprise (employment in the range of 50–250 people) with over 60 years of history. At present, the company produces mainly jams, marmalades and preserves, primarily from apples, plums, cherries and strawberries.

### CSO data analysis

In the first step of the analysis, we chose six most popular Polish fruits based on the CSO data. These are apples, strawberries, cherries, currants, plums and raspberries. The production of these fruits is equal to 94.8% of total fruit production in Poland (Table 1 contains accurate quantitative data on the amount of production of these fruits).

In the second step, we analysed the distribution of each of selected fruits production. There are three ways of distribution of fruit production: direct consumption, export and processing. In the context of the discussed topic, processing is the most important one, as waste is highly generated in processing plants. Table 1 shows the data on the distribution of each of selected fruits. As it can be seen, the majority of each fruit type, excluding plums, is intended for processing.

Above data was used to obtain the amount of waste generated in the processing of each of selected fruits, taking into account processes specific for each fruit. For example, strawberries or raspberries do not require stoning, which is unavoidable in case of processing cherries or plums. The data on the specificity of production has to be also considered,

as the manufacturing of various products generates different amounts of waste. For example, up to 95% apples in Poland are intended for pressing. The obtained results are shown in the next chapter.

The CSO data was also analysed in terms of Polish energy balance, both heat and electricity. The electricity balance is understood as a comparison of total production, import, export and consumption of electrical energy in Poland, from all sources (i.e., coal, gas, other fuels and renewable energy sources). The heat balance should be understood similarly but in case of heat, no import or export is possible. That data, shown in Table 2, will provide a reference point for energy that might be produced using waste from fruit processing.

### Case study

The case study was based on 5 years data preceding the study. Average fruit purchases in the surveyed production plant are as follows:

- apples—564.3 Gg,
- strawberries—253.3 Gg,
- cherries—171.2 Gg,
- plums—987.2 Gg.

As it can be seen, the proportion of fruit used in the given production plant is different from that of the country (Table 1). The plant uses a larger share of stone fruits, what leads to an immediate conclusion that the waste in the form of stones will constitute the main potential source of energy.

To analyse the potential share of energy obtained from the waste in the surveyed plant energy balance, the data on its energy consumption are needed. The average energy consumption, both heat and electricity, in the plant under study is as follows:

**Table 2** Polish balance of heat and electricity in 2016

	Heat (PJ)	Electricity (PJ)/(TWh)
Production	294.2	599.76/166.6
Imports	–	50.4/14
Exports	–	43.2/12
Consumption	294.2	606.96/168.6

**Table 1** Production and distribution of fruits in Poland (2016)

	Apples	Strawberries	Cherries	Currants	Plums	Raspberries	Others
Production (Gg)	3168.8	204.9	179.4	159.9	94.9	79.9	212
Processing (%)	58	68	85	92	26	77	–
Consumption (%)	20	27	11	4	61	8	–
Export (%)	22	5	4	4	13	15	–

- electricity—1,014,192 MJ/281,720 kWh,
- heat—14,256,000 MJ.

The above data show that studied facility consumes on average more than 1,000,000 MJ (i.e., 277,778 kWh) of electric energy and more than 14,000 GJ of thermal energy each year. Most of the machines used in the surveyed processing plant are supplied by heat in the form of technological steam. The average annual amount of burned coal is 1080 Gg. Electricity is mainly used for production purposes (the biggest load is the aseptic packaging line with installed power at the level of 50 kW), but also in offices and social rooms, as well as for lighting the entire production plant.

The next chapter, after the analysis of national energy potential of waste from fruit processing, shows the analysis of using the waste generated in the plant under study in the context of decreasing the external energy demand.

## Results

### Analysis of energy potential of fruit waste in Poland

Table 3 shows the results of calculations of amount of waste generated in the processing of selected fruits in particular processes.

**Table 3** The share and amount of waste generated in the processing of selected fruits by particular processes

	Apples	Strawberries	Cherries	Currants	Plums	Raspberries
Processed amount of fruits	1837.9	139.3	152.5	147.1	24.7	61.5
Sorting						
Share (%)	0	100	100	100	100	100
Amount of fruits	0	139.3	152.5	147.1	24.7	61.5
Share of waste (%)	–	0.5	0.5	0.5	0.5	0.5
Amount of waste	0	7	7.6	7.4	1.2	3.1
Stoning						
Share (%)	–	–	100	–	100	–
Amount of fruits	–	–	144.9	–	23.4	–
Share of stones (%)	–	–	20	–	16	–
Amount of stones	–	–	29	–	3.8	–
Pressing						
Share (%)	95	24	35	64	–	43
Amount of fruits	1746	31.8	40.6	89.4	–	25.1
Share of waste (%)	21	20	28	18	–	20
Amount of waste	366.7	6.4	11.4	16.1	–	5
Pureeing						
Share (%)	5	–	–	–	–	–
Amount of fruits	91.9	–	–	–	–	–
Share of waste (%)	6	–	–	–	–	–
Amount of waste	5.5	–	–	–	–	–

Amounts of fruits and waste are given in thousands of tons [i.e., (Gg)]

Table created based on CSO data, as well as [19, 20]

Waste is obtained in two forms. The first are stones, the second is waste from sorting, pressings and pomace, etc. Each of these forms can be utilized in different ways, as it is shown in below subsections.

It should be added that Table 3 does not include freezing, which is also considered as fruit processing but in contrast to sorting and stoning it does not generate any waste, but of course, this process still consumes energy.

### Stones

The analysis of results from Table 3 shows that there are 32.8 Gg of stones from cherries and plums, which can be used for energy purposes. Stones, after pre-drying and crushing, are good substrates for burning in biomass boilers [21, 22]. Results of the energetic analysis of such substrates are shown in Table 4. Due to the unavailability of exact data, we assumed that the parameters characterizing stones from plums are close to parameters of cherry stones, which we draw from Rzeźnik et al. [22]. This assumption should not introduce significant differences in results due to the generalized similarity of properties of both substrates [23].

**Table 4** Analysis of the Polish energy potential of stones from cherries and plums

	Value
Amount of stones (Gg)	32.8
Amount of stones after pre-drying (Gg)	23.5
Moisture content of pre-dried and crushed stones (%)	5.8
Lower heating value (MJ kg <sup>-1</sup> )	19.2
Combustion efficiency (%)	80
Energetic potential (GJ)	360,960

### Waste from sorting, pressings, pomace, etc.

The sum of waste from Table 4 amounts to 437.3 Gg. This waste can be used for methane production in the process of methanogenesis [8, 9, 24]. Table 5 shows the results of such analysis. We assumed that obtained methane could be utilized in cogeneration unit to produce heat and electricity. 38% efficiency of electricity production and 43% of heat production were assumed. The fact that the contribution of produced power (30% of heat and 10% of electric power) must be used for the technological processes was taken into account. The parameters of methanogenesis and data on the cogeneration process were drawn from Kowalkowski [20] and Kowalczyk-Juško [24].

### Case study results

Table 6 shows the data obtained from the processing plant under study, concerning the amount of waste generated in the processing of particular fruits. All the data shown below are based solely on the information obtained from the management and staff of the surveyed processing plant.

The next steps of the performed analysis, shown in below subsections, are analogous to the steps shown in the “Stones” and “Waste from sorting, pressings, pomace, etc.”, so the

**Table 5** Analysis of the Polish energy potential from utilizing fruit waste for biogas production

	Value
Amount of waste (Gg)	437.3
Potential of methane production for fruit waste (m <sup>3</sup> Gg <sup>-1</sup> )	380,000
Yearly methane production (m <sup>3</sup> )	44,866,980
Heating value for methane (MJ m <sup>-3</sup> )	33
Working time of biogas plant per year (h)	8000
Efficiency of heat production (%)	43
Theoretical heat power output (MW)	22.11
Theoretical yearly production of heat (GJ)	445,664
Efficiency of electricity production (%)	38
Theoretical electric power output (MW)	19.54
Theoretical yearly production of electricity (GJ)/(MWh)	506,369/140,658

**Table 6** The share and amount of waste generated in the processing of selected fruits by particular processes in the processing plant under study

	Apples	Strawberries	Cherries	Plums
Processed amount of particular fruits (Mg)	564.3	253.3	171.2	987.2
Sorting				
Share (%)	0	100	100	100
Amount of fruits (Mg)	0	253.3	171.2	987.2
Share of waste (%)	–	0.5	0.5	0.5
Amount of waste (Mg)	0	1.27	0.86	4.94
Stoning				
Share (%)	–	–	100	100
Amount of fruits (Mg)	–	–	170.34	982.26
Share of stones (%)	–	–	20	18
Amount of stones (Mg)	–	–	34.07	176.8
Pureeing				
Share (%)	100	–	–	–
Amount of fruits (Mg)	564.3	–	–	–
Share of waste (%)	3	–	–	–
Amount of waste (Mg)	16.93	–	–	–

same data concerning parameters of processes of burning the stones, methanogenesis and cogeneration were used.

### Stones from cherries and plums

Data from Table 6 shows that there are almost 211 Mg of stones from cherries and plums. Results of the analysis of the energetic potential of waste burning are shown in Table 7.

### Waste from sorting and pureeing

The sum of that waste from Table 6 amounts to 23.99 Mg. Table 8 shows the results of analysis of using the waste for methane production and then utilizing it in a biofuel-fired cogeneration unit, i.e., CHP (combined heat and power)

**Table 7** Analysis of the surveyed processing plant energy potential from stones

	Value
Amount of stones (Mg)	210.88
Amount of stones after pre-drying (Mg)	151.1
Moisture content of pre-dried and crushed stones (%)	5.8
Lower heating value (MJ kg <sup>-1</sup> )	19.2
Combustion efficiency (%)	80
Energetic potential (MJ)	2320.9

**Table 8** Analysis of the surveyed processing plant energy potential from biogas production

	Value
Amount of waste (Mg)	23.99
Potential of methane production for fruit waste (m <sup>3</sup> Mg <sup>-1</sup> )	380
Yearly methane production (m <sup>3</sup> )	2461.37
Heating value for methane (MJ m <sup>-3</sup> )	33
Working time of biogas plant per year (h)	8000
Efficiency of heat production (%)	43
Theoretical heat power output (kW)	1.1
Theoretical yearly production of heat (GJ)	24.45
Efficiency of electricity production (%)	38
Theoretical electric power output (kW)	0.98
Theoretical yearly production of electricity (GJ)/(kWh)	27.78/7.72

engine allowing simultaneous production of heat and electricity.

## Discussion

Fruit waste, in the context of the possibility of using it in the production of energy, can be divided into two groups. First are stones, which are very good substrate for combustion in biomass boilers. Stones can be also co-fired with coal. They can be retrieved mainly from cherries and plums in Poland. The second group is moister waste, being a by-product of sorting, pureeing, and pressing. It can be used to produce biogas and then, in our opinion, the best solution in economical aspect is utilizing it in a biogas CHP unit to produce heat and electricity.

The results obtained in the previous section shows that total heat energetic potential from fruit processing industry in 2016 was equal to 806,624 GJ (44.75% from stones and 55.25% from biogas), while total electric energetic potential is equal to 506,369 GJ (140,658 MWh). These values, when compared to the total heat and electricity consumption in Poland (294.2 and 606.96 PJ (168.6 TWh), respectively) can

be considered negligible (0.27% of total heat consumption and 0.08% of total electricity consumption, i.e., 0.15% of total Polish energy consumption in 2016), but the environmental factor can not be ignored. That is the main reason why the utilization of post-production waste from fruit processing should be a topic of interest, as it works two ways, i.e., through reducing the amount of waste and simultaneously increasing production of renewable energy and so does its share in national energy balance.

The total amount of waste in the tested processing plant is approximately 235 Mg, of which almost 90% are stones from cherries and plums. These can be used for combustion in a biomass steam boiler, which might support the steam usage in processing plant. Due to the large quantity of stones produced in the plant, they can not be used through co-firing with coal in existing coal-fired boilers, as they would add 20% by weight of carbon and so such co-firing would then be inefficient because of different combustion characteristics of both fuels. The energy that can be generated by burning of stones can produce 2321 GJ of thermal energy, which would cover more than 19% of the heat demand of the plant. In such a way, the annual consumption of coal in the surveyed plant can be decreased by over 200 Mg. In the analysis of the potential use of the rest of the waste for the purpose of biogas production, it was found that obtained amount of waste is too small to make the possible investment in a small biogas plant profitable. That analysis, in comparison with the data on the Polish national potential, leads to the following conclusions:

- Individual processing plants of fruit processing industry can have very different proportions of produced waste, and so the analysis of the potential use of waste for energy purposes in each particular case should always take into account these differences, as well as existing installations, like e.g., type of boilers being used in the analysed plant.
- Sometimes, the delivery of moist waste to external biogas plants can be a better option than investing in an on-site biogas plant. Another idea is to create one biogas plant that recycles waste from many companies.
- Waste in the form of fruit stones can be co-fired with coal (in case of companies processing small quantities of stone fruits), fired independently (like in the case of surveyed plant) or even intended for sale (after pre-drying).

The analysis of data from the surveyed processing plant shows that case study analysis may point to problems that are often unnoticeable in the countrywide analysis.

It should be also noted that generally, fruit processing industry is very difficult organizationally, primarily due to unevenness of yields and very short lifespan of fruits [19], especially considering unpredictability of phenomena such



as droughts, floods or crop plagues. Therefore, the degree of biomass use on a local scale depends largely on the correct evaluation of local production capacity [25], but the unpredictability of yields does not allow for an accurate estimate of the substitutability of conventional energy sources with renewable energy produced through waste utilization.

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