SCALEUP
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bioeconomy development

# Task 2.3 Regional Biomass and Nutrient Availabilities in Mazovia, Poland

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## 1.1 Introduction

### 1.1.1. Background

The Mazowieckie voivodeship (Mazovia Region) with Warszawa (Warsaw) - the capital of Poland - is located in the central part of Poland and covers an area of more than 35,500 square kilometers.

According to Statistics Poland, apart from being the largest province in Poland in terms of area and population with 5 425 028 inhabitants, the region is the fastest developing region of Poland. It is characterized by low unemployment, high economic development speed and young and well qualified staff. The development of entrepreneurship in the region is primarily influenced by the existence of business incubators, including academic business incubators, highlighting the transregional role of Warsaw, connected to its role as the capital city of Poland. In terms of technology and innovation ecosystems, there is a high availability of innovative solutions (including Industry 4.0) and there are strong and active clusters operating in traditional and high-tech industries. Research, private and non-governmental organizations can count on tangible support from the regional government for agriculture development, as well as the availability of EU instruments and financing schemes. Mazovia is also one of the most internally diverse areas in Poland showing high internal diversification with a nationwide potential in nearly every field: science, research, education, industry and infrastructure.



Figure 1. Mazovia region map against the map of the country


*Source: Adapted from https://www.paih.gov.pl/polish_regions/voivodships/mazowieckie#*

On 1 January 2018, Mazovia region was divided into 2 statistical units of the NUTS2 level ("regions" according to the systematics used by Eurostat):

- Region warszawski stołeczny (Warsaw Capital), which includes the city of Warsaw together with the following powiats: grodziski, legionowski,miński, nowodworski, otwocki, piaseczyński, pruszkowski, warszawski zachodni and wołomiński,
- Region mazowiecki regionalny (Mazovia region), which covers the rest of the Mazovia region

Figure 2. Mazovia region division according to NUTS2


*Source: https://innowacyjni.mazovia.pl*

The Mazovian economy is characterized by high industry diversification, being less dependent on cyclical fluctuations than regions uniform in terms of the structure of the economy. There is also a clear regionalization of certain specializations.

Agriculture is one of the most important sectors in the Mazovia and it is characterized by very fertile soils enabling a thriving development of agricultural economy. Usable agricultural land covers about 65% of the area, hence the large role of horticulture, orcharding and related activities (source: Statistics Poland; stat.gov.pl).

Poland is the largest producer of apples in Europe. Apples have been grown in Poland since the 12th century, and today form an integral part of its economy and economic heritage.



Figure 3. Apple harvesting in Poland

*Source: own picture.*

According to PolishFoodies (polishfoodies.com), in 2021, Poland produced 4,170,000 tons of apples, almost 22% more than in 2020 which put the country on the top of the EU apple-producing charts.

Taking into account the above-mentioned facts and aspects, several possible bio-based solutions have a chance for the development in the Mazovia region, including:

- production of new functional agri-food products;
- production of new bio-based packaging;
- production of fertilisers based on waste from fruits, grains and vegetables and
- other processing activities.

In order to facilitate the development of new bio-based solutions, it is worth to have in mind financing opportunities available currently in the Mazovia region and related to the EU funds 2021-2027.

The development of possible bio-based solutions should be in line with the RIS 2030 – a strategic framework for the regional innovation ecosystem and smart specialisation of the Mazovia region (Mazowieckie voivodeship). It constitutes a signpost along the paths of regional innovation development and enables better use of the region's resources in the area of research, innovation development or cooperation of entrepreneurs and scientific entities, business support institutions and administration.



In Mazovia region, four main thematic areas are adopted as the basis for the specialisation, on the foundation of which the entrepreneurial discovery process is organised. The four areas are as follows:

1. Safe Food
2. Smart systems in industry and infrastructure
3. Modern business ecosystem
4. High quality of life

For each area of smart specialisation, the assumed economic effects and expected project results were defined, as well as sample technologies supporting the area.

Safe Food is one of RIS2030 specialization areas that focuses on ensuring high quality agri-food products that are safe for consumers and the environment. This can be achieved, by among other ways, through improving products and processes related to their production, processing, storage, distribution and disposal.

The area includes solutions affecting food quality and safety, among others, in the field of:

- farming and breeding techniques (including precision farming),
- fertilisers, plant protection products, feeding stuffs, veterinary medicines,
- machinery, equipment and tools for agriculture and agri-food processing,
- formulation of food products and improvement of technological processes,
- quality testing of agri-food products,
- food storage and distribution (including packaging)

Examples of technologies supporting the area of specialisation:

- Agritech - technologies dedicated to agriculture, both plant and animal production up to the first processing stage.
- Biotech - technologies using biological processes on an industrial scale.
- Foodtech - technologies dedicated to food production from the first processing of agricultural products.
- Qualitytech - technologies and solutions used in quality control.

The smart specialisation of the Mazovia is open, as it assumes the possibility of identifying new development niches at any time of the smart specialisation strategy implementation within so called entrepreneurial discovery process. This approach is crucial to involve stakeholders (including entrepreneurs) as broadly as possible directly in the process of creating, implementing, monitoring, evaluating and updating the strategy for smart specialisation.

Additionally, the Strategic Plan for the Common Agricultural Policy 2023-2027 (CAP SP 2023-2027) prepared by Poland and approved by the European Commission should be taken into account as well. It provides an opportunity to effectively, and sustainably strengthen the competitiveness and development of Polish agriculture and rural development, taking into account aspects of the transition to a green and digital economy.

### 1.1.2. Scope

According to Agronomist.pl[1], Poland is the largest apple-growing country in the European Union, and the fourth largest producer in the world (after China, USA and Turkey). The two selected value chains are related to apple production – apple pruning (branches) and apple pomace.

The first value chain – apple pruning residues - belongs to the agricultural wastes generated in the agro-food processing sector. Annual pruning is required, and thus generates a substantial number of residues, which must be disposed of. The second one – apple pomace- is left-over solid residue resulting from extraction of juice from apples.

In terms of quality, Polish producers concentrate on high quality of produced apples. They have access to modern cold stores and can offer fresh apples during the whole year. The main investments in apple production are related to the modern storage, sorting and packaging facilities. It's financed mostly by the groups of producers in the regions. Suppliers very often consolidate in associations and are able to plan, sort, pack and supply big, uniform batches of apples. It is noticed that labour resource costs are lowered by hiring workers from East European countries out of the EU.

According to Polish Foodies, there are several types of apples grown in Poland. It is possible to distinguish (polishfoodies.com):



Figure 4. Mutsu apples grown in Poland

*Source: own picture.*

- Popular Polish apple varieties, that include Kostzela (old apple variety with a greenish peel), Antonówka (sour and crumpbly variety coming from Russia that withstands frost), Złota Reneta (perfect for kompot and jam), Kronselska (green, yellow and aromatic), Papierówka or Oliwka Żółta (semi-sweet-semi-sour yellow apples originated in the Baltics perfect for coocking)

[1] Agronomist.pl is online platform with professional knowledge and innovative tools for agricultural producers and food processors.

- Modern varieties, that include Idared (tart and juicy), Jonagored (slightly sour with a juicy aromatic yellow pulp), Jonaprince (large, crisp, juicy, and sweet), Mutsu (a hybrid of Indo and Golden Delicious, conical in shape and slightly sour, but creamy), Szampion (also called champion, developed in the Czech Republic), Ligol (large and creamy) and Delikates (perfect for desserts).

- International apples, Royal Gala (originally from New Zealand sweet and tender apples started to being cultivated in 90s in Poland), Golden Delicious (aromatic and sweet with a crispy creamy flesh), Pink Lady (Australian cross-breed with sweetness of Golden Delicious and the firmness of Lady Williams apples), Gloster (German apples with tasty flushed red fruit) and Granny Smith (firm juicy Australian apple).

The most popular varieties in Poland are: Idared (21,6%), Jonagold (17,5%), Champion (11,2%), Ligol (7%), Golden Delicious (5,1%), Gala (5%), Gloster (4,8%), Lobo (2,3%). 64% of apples produced in Poland are dedicated to consumption and 36% for industry[2].



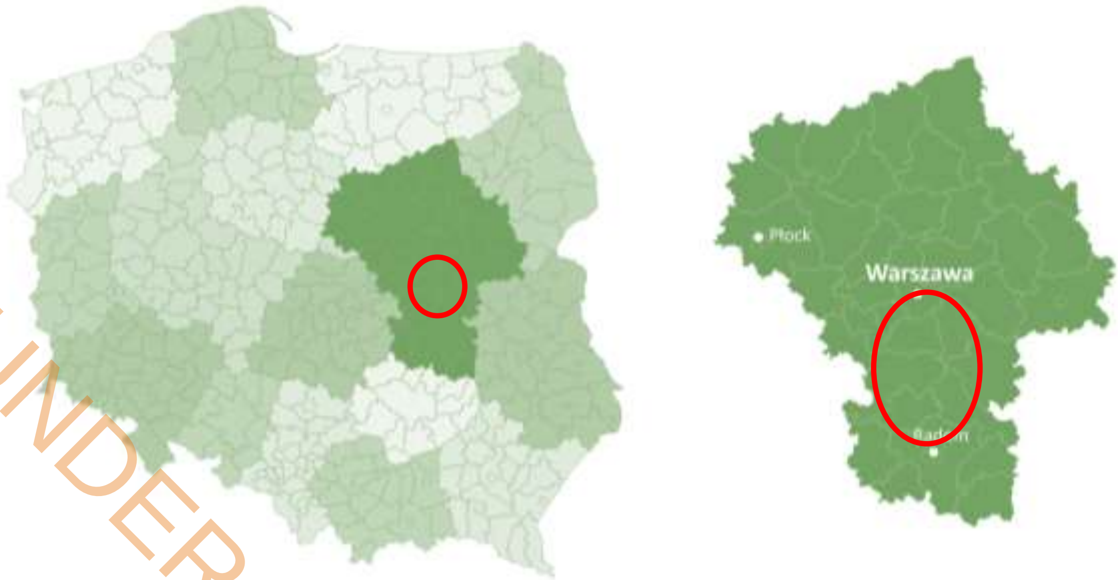
Figure 5. Apple orchard in Poland

*Source: own picture.*

In relation to the locations, on average, more than 45 percent of the country's apple production comes from the Grojec-Warka region, known as "Europe's largest orchard." Municipalities with the highest concentration of crops are: Błędów, Belsk Duży, Grójec and Warka. Mazovia region has the largest continuous apple orchards area in Poland that covers 68.816 ha.

Figure 6. Main apple production in Mazovia region

[2] Pietrzak, Michał, Aleksandra Chlebicka, Paweł Kraciński, and Agata Malak-Rawlikowska. 2020. "Information Asymmetry as a Barrier in Upgrading the Position of Local Producers in the Global Value Chain—Evidence from the Apple Sector in Poland" *Sustainability* 12, no. 19: 7857. https://doi.org/10.3390/su12197857




*Source: own elaboration based www.innowacyjni.mazovia.pl*



Polish orchards are set up on the lowland areas, mostly placed on soils made of clays, dust formations and saprophytic sands that gives good oxygenation to significant depths. The level of pH is between 6,1 - 6,7.

The country is situated in moderate climate zone which is very favourable for apple trees. Average temperature from flowering to harvesting time is 16,3 C (with rainfall 615 mm / month) and 2,7 C (with rainfall 320 mm / month) in the vegetation period. In terms of production methods, the central region of Poland has a very good relation of cold and hot days during the year, what makes good balance of sweet and sour taste.

Apple production in Poland in recent years has distinguished itself from other fruit production sectors by gradually increasing production efficiency per unit area, with decreasing production costs. Intensification of orchard production requires the use of an adequate amount of agrotechnical treatments (fertilization, chemical plant protection), which can have a negative impact on the quality of the environment, especially in relation to soil, surface water, groundwater and biological balance.

Polish apple producers are mostly small companies with less than 5 hectares areal (89,3% of all producers). In each region, they set up local trade groups, which associate most of the local suppliers. In terms of commercialization, trade groups are responsible for the sale of the apples but also they store the fruits, sort, pack and organize the transport. They negotiate the prices and the cooperation conditions. The producers with the acreage above 5 hectares (10,7%) mostly work independently and they sell and export the apples directly to the buyers.

Residues of mineral fertilizers and pesticides may cause deterioration of the quality of the environment and produced food. This is why in the interest of producers and consumers of agricultural products, it is necessary to ensure the proper use of the agroecosystem within the framework of integrated fruit production, meaning the appropriate number of agrotechnical treatments, doses and timing of their application, grace and prevention periods), taking into account the balance of economic, social and natural interests.

According to LabManager, Apple trees need access to important nutrients, which come from the soil. However, soil is quite different from orchard to orchard[3].

[3] www.labmanager.com

**Apple prunings**

In terms of the role of nutrients in the value chain, woody residues are the most promising source of raw materials for the wood industry and could replace traditional wood assortments for bioenergy and industrial use. Additionally, prunings could be used as a lignocellulosic source for particleboard production. According to research studies, apple pruning residues, as a wooden biomass, could partly replace typical wood assortments for small and middle size boilers and commercial power plants, supporting the energy units with renewable fuel. Moreover, they could generate heat, similar to technologies related to waste-to-energy (WtE), zero waste or circular bioeconomy solutions. It is worth noting that pruning-to-energy (PtE) may be especially important in rural areas that are characterized by limited access to forest resources and a large share of apple orchards in the region.

It is possible to use the pruning biomass as a fertilizer. The prunings should be chipped to capture the nutrients from the orchard's 'waste' and return them to the soil. In terms of innovative applications of nutrients, this topic should be explored, preferably in coordination with research and education institutions.

**Apple pomace**

Apples are a staple fruit grown in temperate climate zones, are among the most widely consumed fruits in the fresh state and are a valued raw material in the processing industry. The fruit is a valuable source of fiber, pectin, vitamins A, B, PP, C, K, which are essential for the human body, as well as carbohydrates (glucose, fructose), organic acids (malic, citric, tartaric) and minerals. The advantage of apples is that they are low in calories, as a medium-sized apple has about 60 kcal.

Apple pomace is a rich source of nutrients such as phytochemicals, as well as carbohydrates, vitamins and mineral. It consists of a high amount of carbohydrates, of which about 70% are simple sugars, have a high source of arabinose and rhamnose and contain from 10 to 12% glucose (dry weight basis), which is a main fuel source for most tissues throughout human body. Besides carbohydrates, apple pomace is also a source of proteins.

Apple pomace is a rich source of many minerals, which are of interest from the human nutritional point of view. Potassium represents the main portion of the total mineral content of apple pomace and provides 20% of Recommended Dietary Allowances (RDA) after consumption of 100g of apple pomace. Sodium and phosphorus are the next most widespread minerals in apple pomace and provides respectively 13% and 11% of RDA[4].

Apple pomace is also rich source of copper and zinc. Copper is requested in correct superoxide dismutase working, which causes neutralization of free radicals in human body. Zinc is essential trace element for humans, and other organisms, after iron is the second most abundant transition metal in organisms.

## 1.2 Biomass Availability

### 1.1.3. Biomass availability – apple prunings

In Europe, the main permanent crop areas are occupied by olive trees, vineyards, and fruit trees. According to research studies, the assumed theoretical potential of pruned biomass from permanent crops in EU28 is ca. 246 PJ per year and apple orchards represent a share in the permanent crops area of 4.2%, accounting for ca. 450,000 ha. Taking into account that the largest apple producer in the

[4] Kruczek, Marek & Gumul, Dorota & Kacaniova, Miroslava & Ivanišhová, Eva & Mareček, Ján & Gambuś, Halina. (2017). Industrial apple pomace by-products as a potential source of pro-health compounds in functional food. Journal of Microbiology, Biotechnology and Food Sciences. 7. 22-26. 10.15414/jmbfs.2017.7.1.22-26.

EU is Poland with over 143,000 ha and almost half the country's production of apples is concentrated in the Mazovia region with 68.816 hectares[5].

Figure 7. Fruit Production in Poland

| Wyszczególnienie Specification | 2020 | 2021 | |
|---|---|---|---|
| | w tys. t In thousand tonnes | | 2020=100 |
| **Ogółem Total** | **3948,6** | **4493,5** | **113,8** |
| Jabłonie Apple trees | 3555,2 | 4067,4 | 114,4 |
| Grusze Pear trees | 61,0 | 68,6 | 112,4 |
| Śliwy Plum trees | 111,7 | 117,4 | 105,1 |
| Wiśnie Sour cherry trees | 155,5 | 166,6 | 107,1 |
| Czereśnie Sweet cherry trees | 51,3 | 59,1 | 115,3 |
| Brzoskwinie Peaches | 3,8 | 4,5 | 120,3 |
| Morele Apricots | 3,1 | 3,1 | 101,2 |
| Orzechy włoskie Walnut trees | 7,0 | 6,8 | 96,6 |


a Fruit harvested in orchards and outside. b Peaches, apricots, walnuts. c Including wild strawberries. d Including thornless blackberry. e Chokeberry, highbush blueberry, vine, hazel and others.

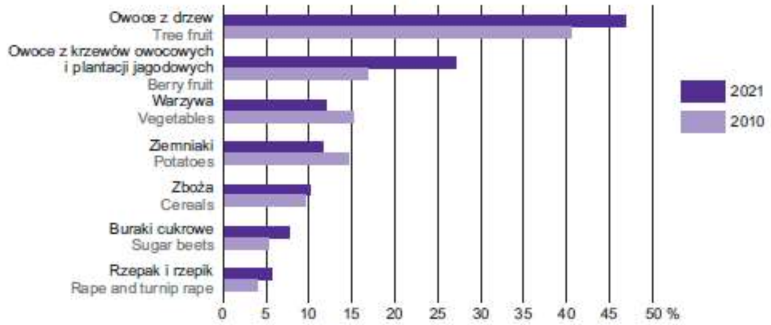
Source: Statistics Poland (GUS), 2022



[5] different-countries-one-environment.pl

WYKRES 2 (57). **UDZIAŁ WOJEWÓDZTWA W KRAJOWEJ PRODUKCJI WYBRANYCH ZIEMIOPŁODÓW ROLNYCH I OGRODNICZYCH**

CHART 2 (57). THE VOIVODSHIP'S SHARE IN DOMESTIC PRODUCTION OF SELECTED AGRICULTURAL AND HORTICULTURAL CROPS




Source: Statistics Poland (GUS), 2022



Figure 8. Fruit Production by voivodship, including Mazowieckie (Mazovia)

TREE FRUIT PRODUCTION IN ORCHARDS BY VOIVODSHIPS

| WOJEWÓDZTWA VOIVODSHIPS | 2019 | 2020 | 2021 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ogółem total | | | jabłonie apple trees | grusze pear trees | śliwy plum trees | wiśnie sour cherry trees | czereśnie sweet cherry trees |
| | w tys. t in thousand tonnes | | | w % ogółem in % of total | | | | |
| **POLSKA** POLAND | **3456,4** | **3948,6** | **4493,5** | **90,5** | **1,5** | **2,6** | **3,7** | **1,3** |
| Dolnośląskie | 30,0 | 21,2 | 35,9 | 64,9 | 3,4 | 16,3 | 7,6 | 5,8 |
| Kujawsko-pomorskie | 64,1 | 54,0 | 60,8 | 77,4 | 3,2 | 6,7 | 8,6 | 3,5 |
| Lubelskie | 529,0 | 573,7 | 611,0 | 89,6 | 1,3 | 3,2 | 5,1 | 0,7 |
| Lubuskie | 13,0 | 10,4 | 75,3 | 94,0 | 0,8 | 1,6 | 2,0 | 0,9 |
| Łódzkie | 464,9 | 632,5 | 575,1 | 90,3 | 1,7 | 2,2 | 4,8 | 0,8 |
| Małopolskie | 107,7 | 120,6 | 132,7 | 88,4 | 2,9 | 5,5 | 1,8 | 0,9 |
| Mazowieckie | 1522,5 | 1822,5 | 2101,8 | 93,7 | 1,4 | 1,1 | 2,6 | 1,2 |
| Opolskie | 4,8 | 4,7 | 11,8 | 88,4 | 2,8 | 1,6 | 2,0 | 3,2 |
| Podkarpackie | 24,2 | 37,3 | 78,0 | 89,2 | 2,9 | 3,7 | 1,2 | 0,4 |
| Podlaskie | 11,6 | 9,2 | 14,3 | 87,2 | 5,3 | 2,1 | 3,3 | 1,4 |
| Pomorskie | 20,7 | 11,8 | 14,5 | 91,3 | 2,2 | 2,0 | 2,7 | 1,7 |
| Śląskie | 6,1 | 6,7 | 12,2 | 82,3 | 7,0 | 5,4 | 2,2 | 1,6 |
| Świętokrzyskie | 500,7 | 529,4 | 593,4 | 87,7 | 0,6 | 4,3 | 5,0 | 1,5 |
| Warmińsko-mazurskie | 12,0 | 8,5 | 9,5 | 71,2 | 9,7 | 10,3 | 7,2 | 1,3 |
| Wielkopolskie | 104,1 | 97,0 | 134,8 | 75,4 | 3,2 | 7,5 | 7,0 | 6,2 |
| Zachodniopomorskie | 40,8 | 9,2 | 32,4 | 87,5 | 2,6 | 6,3 | 1,2 | 1,2 |

Source: Statistics Poland (GUS), 2022.

Figure 9 Crop area, yield and harvesting in Poland and Mazovia region

**AREA OF CULTIVATION, YIELDS, AND APPLE HARVESTS IN ORCHARDS**

| Specification | Area of cultivation (ha) | Yield per 1 ha in decitonnes (dt) | Harvest in decitonnes (dt) | Area | Yields | Harvests |
|---|---|---|---|---|---|---|
| | | | | 2020 = 100 | | |
| | | | OGÓŁEM | | | |
| Polska | 161 948 | 251,2 | 40 673 766 | 106,1 | 107,8 | 114,4 |
| Dolnośląskie | 1 295 | 180,0 | 233 100 | 126,5 | 181,5 | 229,4 |
| Kujawsko-pomorskie | 2 590 | 181,8 | 470 777 | 112,9 | 98,9 | 111,6 |
| Lubelskie | 20 797 | 263,2 | 5 473 884 | 101,3 | 105,2 | 106,6 |
| Lubuskie | 3 769 | 187,8 | 707 911 | 619,8 | 182,0 | 1128,1 |
| Łódzkie | 20 572 | 252,4 | 5 192 426 | 99,3 | 91,5 | 90,9 |
| Małopolskie | 6 110 | 192,0 | 1 173 120 | 104,3 | 108,5 | 113,2 |
| Mazowieckie | 69 816 | 282,1 | 19 695 094 | 99,9 | 114,8 | 114,6 |
| Opolskie | 605 | 172,0 | 104 057 | 224,8 | 144,3 | 324,3 |
| Podkarpackie | 3 852 | 180,7 | 695 976 | 153,3 | 153,5 | 235,4 |
| Podlaskie | 1 012 | 123,6 | 124 995 | 112,5 | 153,2 | 172,3 |
| Pomorskie | 1 300 | 102,0 | 132 620 | 122,8 | 102,5 | 125,8 |
| Śląskie | 813 | 123,4 | 100 323 | 140,8 | 148,0 | 208,4 |
| Świętokrzyskie | 20 725 | 251,0 | 5 201 882 | 103,9 | 109,4 | 113,7 |
| Warmińsko-mazurskie | 853 | 79,5 | 67 779 | 100,3 | 108,9 | 109,2 |
| Wielkopolskie | 4 886 | 208,0 | 1 016 334 | 102,0 | 150,9 | 154,0 |
| Zachodniopomorskie | 2 954 | 96,0 | 283 488 | 406,5 | 163,5 | 665,0 |

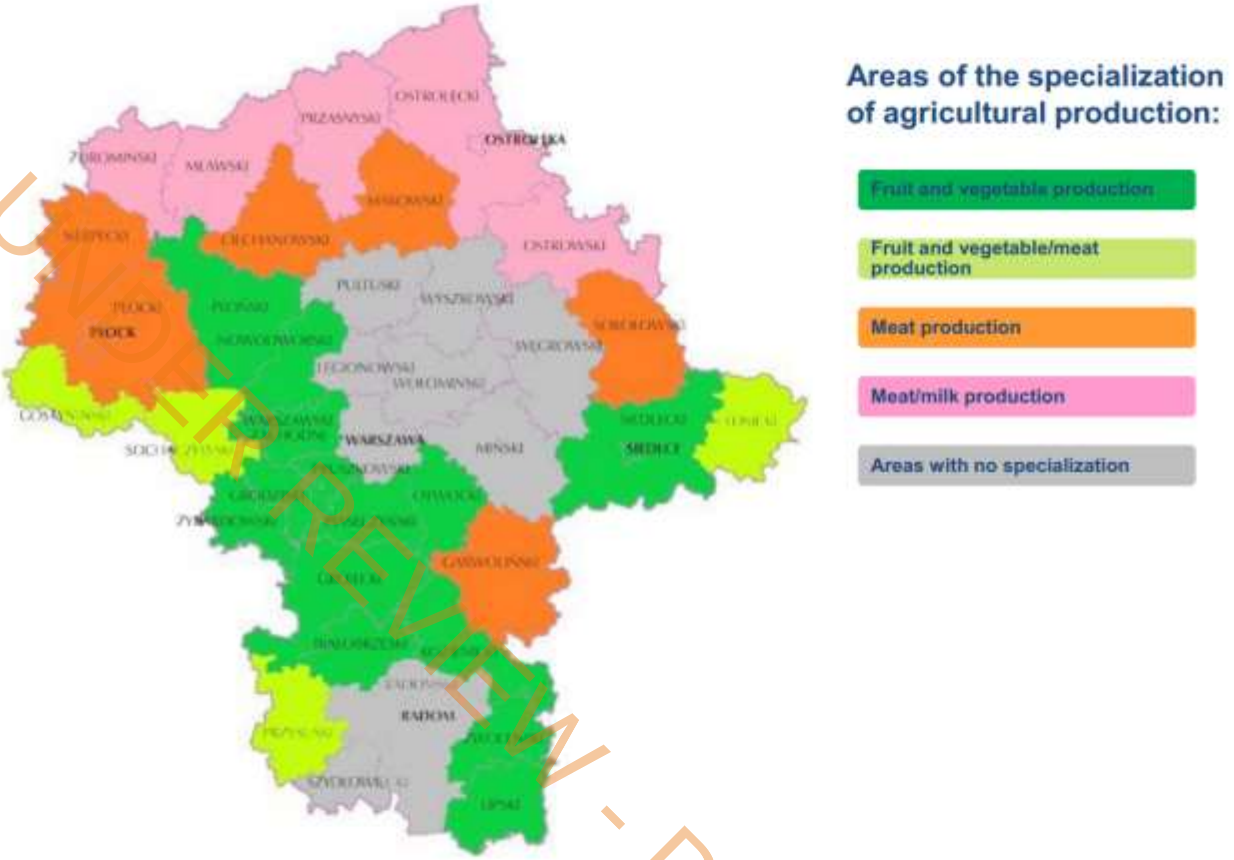


Source: Statistics Poland (GUS), 2020.

Next important regions are Lubelskie District with 22.752 hectares and Świętokrzyskie region with 21.381 hectares and Łódź area 19,512 hectares. In effect, the yearly potential of apple pruning in 28 EU countries is ca. 29 PJ, out of which more than 9 PJ is attributed to Poland[6].

Depending on varieties, the trees are planted in autumn or early spring in rows with 2-4 meters of space in between. The soil must be fertilized in 3-6 months before. Fertilization with nitrogen, magnesium, phosphorus and potassium is necessary during flowering, because they take active part in the process of bud development.

[6] Dyjakon, Arkadiusz & Mudryk, Krzysztof. (2018). Energetic Potential of Apple Orchards in Europe in Terms of Mechanized Harvesting of Pruning Residues. 10.1007/978-3-319-72371-6_58.




Source: Interreg Europe.



According to Kuzin and Solovchenko (2021), potassium (K) is crucial for apple growth, fruit quality, and yield. The apple plant demands it throughout the growing season, peaking during fruit ripening. Currently, themainstream method is through application of the fertilizer to the soils to improve potassium uptake by the rootsand its bioavailability depends on assorted various factors, including pH, interaction with other nutrients in soil solution, temperature, and humidity. Balanced application of potassium is crucial, as its excess leads to competitive inhibition of calcium uptake by plants and the apple fruits affected by the potassium/calciumimbalance frequently develop physiological disorders in storage. New technologies with machine vision might optimize potassium fertilization strategies[7].

[7] Kuzin A, Solovchenko A. Essential Role of Potassium in Apple and Its Implications for Management of Orchard Fertilization. Plants (Basel). 2021 Nov 29;10(12):2624. doi: 10.3390/plants10122624. PMID: 34961094; PMCID: PMC8706047.

The most popular varieties need 140 - 150 days from flowering till harvesting. The potential is growing in accordance with new varieties of low trees and increasing the number of orchards. The intensity of production is picking up above 50 tons/ hectare[8].

During the growth process, required works include:

- Pruning - aimed at shaping the tree and limiting its growth, which in turn affects the better quality of the fruit that the tree produces;
- Digging - performed in order to cover the trunk of the tree and protect it against negative temperatures;
- Fertilization and watering / determining the uptake by the tree of water and nutrients;
- Spraying - protecting fruit trees against diseases, insects and weeds.

In terms of pesticides, they must be controlled and used only when necessary. The chemical composition is regulated with the appropriate regulations.

According to Dyjakon (2019) there are different management options in apple orchards (Figure 10)[9]. One of the field-based agricultural residues involves cut branches from regular permanent tree crop pruning, such as apples. Amongst permanent fruit crops in Poland, apple orchards cover the largest area, resulting in theoretical energy potential of 9.3 PJ per year. Although these agricultural residues might be used as fuel, large amounts are wasted via open dumping or open burning in the field and, therefore, are referred to as waste agricultural biomass. As such, use of these materials for energy applications would be an effective way of managing the waste, while becoming a useful resource rather than a waste material under conventional management practices (Dyjakon, 2019).

Figure 10. Management options in apple orchard


*Source: The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications, 2019*

Pruning is an important cultivation technique that impacts the fruit quality and usefulness of disease control practices. The most popular technique is harvesting and baling of pruned biomass and chipping.

[8] Dyjakon A. Harvesting and Baling of Pruned Biomass in Apple Orchards for Energy Production. *Energies*. 2018; 11(7):1680. https://doi.org/10.3390/en11071680
[9] Dyjakon A. The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications. *Energies*. 2019; 12(4):632. https://doi.org/10.3390/en12040632

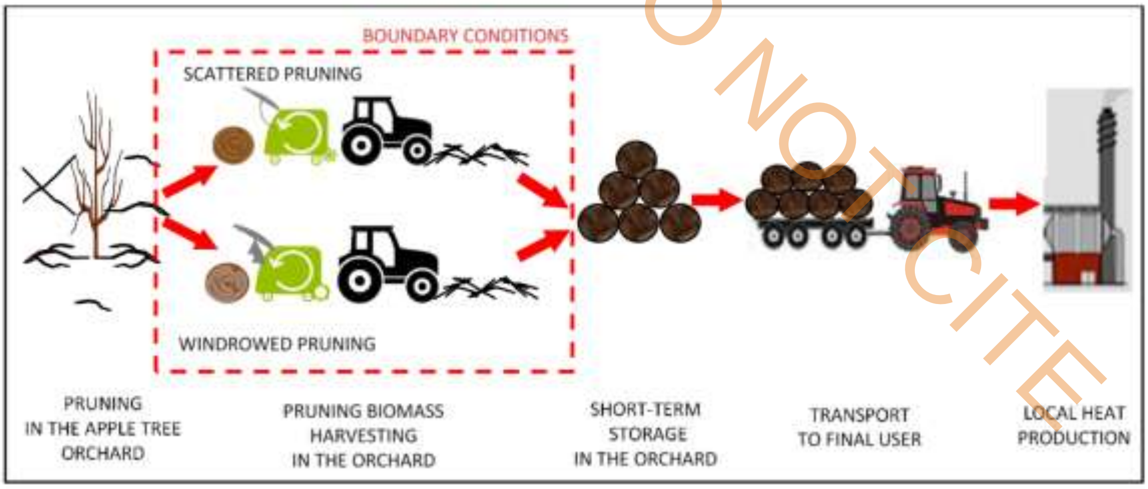
Figure 11. Apple tree pruning baling

*Source: https://www.gospodarstwo-sadownicze.pl/w-zgodzie-z-natura*

Pruned biomass bailings can easily be stored in bales on the field site in the open air at a low-cost. It is related to the fact that there is still much free space for air flow, natural drying takes place, leading to the decrease in moisture content to a level acceptable for energetic use.

Storage of apple pruned biomass in baling is an important part of the logistic chain and could include different options, like open air storage, under cover storage, storage tank, silo, storage with drying, etc. In terms of places, the storage could take place in the orchard, at the final consumer, but there is also an option of mobile pruning services offered to farmers. The use of apple pruned biomass for energetic purposes requires some energy input, manpower engagement, and investment in indispensable machinery.

Figure 12. Pruning-to-energy process




*Source: The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications, 2019*

The process includes the following stages: harvesting, baling, on-site storage, loading, storage, loading, and transportation to the final user. In the logistic chain of prunings-to-energy, a crucial issue is transportation.

The distance between the orchard and the final consumer, as well as the amount of pruned biomass to be transported, is of critical importance in the estimation of the total costs of the supply chain. It seems that for biomass utilization in the small and middle size boilers the distance should not exceed 50 km (preferably below 25 km).

It is important to highlight that apple pruned biomass baling should be done by machinery adapted to the type of tree and the total logistics costs of the whole chain including pruned biomass harvesting, storage, and transportation to the final consumer must be lower than the incomes from the biomass selling.

According to Dyjakon (2019), the cost estimation of the harvesting process in the apple orchard included purchasing cost, service life, machinery usage, while operating costs included fuel consumption and pruning biomass yield. A labor cost of €19.0 h−1 was assumed as an average value in the agricultural sector in the European Union (EU), although the cumulative labor cost of agriculture in Poland is ca. €6.0 h−1. This very conservative approach was applied to display a safe margin of the total costs on the farmer's side, as well as to allow a more realistic comparison of the results against the background of the European bioenergy market[10].



Figure 13. Estimation of the harvesting process in the apple orchard

| Parameter | Unit | Tractor John Deere 5075 GV | Baler SIMPA Z279/1 Classic |
|---|---|---|---|
| Power | kW | 54.0 | - |
| Investment | € | 37,000 | 15,000 |
| Service life | yr | 15 | 10 |
| Trial work | SMH·yr$^{-1}$ | 1500 | 500 |
| Resale | % | 20 | 28 |
| Interest rate | % | 7 | 7 |
| Inflation rate | % | 2 | 2 |
| Taxes, insurance, and housing | % | 1 | 1 |
| Labor cost | €·h$^{-1}$ | 19 | - |
| Fuel cost | €·dm$^{-3}$ | 1.3 | - |
| Lubricant cost | €·dm$^{-3}$ | 5 | 5 |
| Repair and maintenance factor * | % | 80 | 50 |

SMH—scheduled machine hours (the operation time of the machinery (including delays)); * in accordance with Reference [11].

*Source: The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications, 2019*

It is important to highlight that the costs and pruning biomass potential in apple orchards depend also on other factors, such as orchards age, apple variety, density of plantings, harvested machine operation, experience of the workers, etc. As a result, different amounts of pruned biomass might be harvested by the machine set. The decision about the way to proceed with pruned residues should be supported by a case-specific analysis to make a right decision. The pruning harvesting for energetic purposes is strongly influenced by the management strategy in the apple orchard. Pruning harvesting can at least reduce the costs of orchard cleaning. With proper management, the income from biomass sale can be significantly higher, leading to a lowering of the total apple production costs. The orchard management is a critical parameter affecting energy recovery, as well as financial returns.

According to research studies, the available collected biomass potential is an amount of 0.69 tDM·ha−1 per year. Pruned biomass analysis showed a moisture content of 45.1% in the fresh material, the ash

[10] Dyjakon A. The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications. *Energies*. 2019; 12(4):632. https://doi.org/10.3390/en12040632

content was 0.8% dry mass, and the lower heating value was 18.05 MJ·kg−1 dry mass. Total production cost, including all steps and avoided cost of mulching, was 74.7 €·t−1 dry mass. The net energy balance of this value chain was very positive, giving a value of ca. 12,000 MJ·ha−1 per year. This is why the yearly harvested pruned biomass may be considered a good energy source for local heating systems. For the agriculture region, it might be one of the potential solutions in the process of replacement of fossil fuels with renewables and for fostering improved energy efficiency in production processes. This way, biomass might be also a contributor to the renewable energy targets.

There is no additional statistical data on the use of apple prunnigs in the Mazovia region. According to information from producers cooperating with the cluster, most of them are sold for energy purposes. There are no composting plants in the region that would allow the use of this waste as a raw material for the production of natural fertilizers, reducing the consumption of artificial fertilizers used for production in orchards.



### 1.1.4. Biomass availability – apple pomace

In 2021, Poland produced 4,170,000 tons of apples and more than half of them is processed, generating a solid residue called apple pomace. On average, nearly 75% of apple fresh weight is supposed to be extracted as juice during juice production, and the leftover is collected as food waste, the so-called pomace.

Apple pomace is a left-over solid residue resulting from extraction of juice from apples in apple juice concentrate, cider, jams etc. that accounts for ~25% of total apple weight.

In Poland, about 65% of processed apples rely on juice pressing causing the residues, which the biggest part is apple pomace. The apples can also be processed into clear apple juice concentrate, cider, canned as fresh slices/cubes, baby foods, apple butter, jelly, vinegar etc.

Currently, apple pomace is mostly used as animal feed, but the price ranges from 430 to 550 EURO per tonne[11]. However, it is an unprocessed raw material derived from production waste, the value of which, after processing, may increase by using its potential. The apple pomace can be applied directly or after minimal processing as functional ingredients in various types of food products. For example, apple pomace can improve the dietary fiber content and health-promoting properties of bakery products, such as bread, sweet bakery products and brittle bakery food. Apple pomace can also be incorporated with extruded food and meat products to enhance their nutritional value. Additionally, the utilization of apple pomace in confectionery products and dairy food was found to have contributed to the product quality characteristics. Moreover, it can also be used as a part of the substrate for alcoholic beverage development and edible mushroom cultivation. Further potential applications as flavouring and stabilizing agents were also apparent. In addition, many functional bioactive compounds that are extracted from apple pomace, including pectin, phenol and fiber, can also be utilized in food products to improve the product quality and nutritional properties.

Considering the large volume of this by-product generated from the production and processing of juice, the commercial applications of pomace can create great economic impact, but it is important to highlight that is also characterized by high water content and a tendency to rot quickly, so as an unstable waste, apple pomace pose a high risk of biological contamination. Using it as a source of energy in agricultural biogas plants might be considered as an alternative and a safe and effective way to manage them.

On the other hand, however, apple production waste is characterized by a high content of biologically active components valuable for human and animal nutrition, such as vitamins and polyphenols. Polyphenols are natural compounds with antioxidant activity, showing anti-inflammatory, antiviral and anticancer properties. They could be successfully recovered and used in food and feed production processes. The use of fruit and vegetable pomace for biogas production means that these components are irretrievably lost.

Taking into account that the costs for apple pomace waste management is very high, while the recovery rate is relatively low, the recovery should be done as close as possible to the production site. It is also

[11] Average prices based on market offers (own calculations based on current seller offers)

motivated by the fact that composting of apple pomace creates secondary pollution due to greenhouse gasses production, as well as creates surfaces for human disease vectors to breed, and it has the potential to contaminate ground waters.

In Mazovia region, Apple processing plants are located in different parts region, with a concentration in the Grojec area. Examples of apple juice factories are:

1. Nasza Tłocznia - https://naszatlocznia.pl
2. Sad Sok - https://www.facebook.com/SadSokTlocznia/
3. Tłocznia Bankiewicz – www.soki-naturalne.eu
4. Naturalne Tłoczone - https://naturalnetloczone.pl
5. Royal Apple - https://royal-apple.com/kontakt/



## 1.3 Nutrient Availability

### 1.1.5. Nutrient availability – apple prunings

In terms of apple orchards, nutrients are located mostly in fruits leaves, fruits, roots and pruning wood. The practice of pruning can have an indirect impact on the nutrient distribution and overall health of an apple tree because by removing excess, dead, or diseased branches, pruning helps the apple tree to allocate its resources (including nutrients and water) more efficiently to the remaining branches and fruit, which can lead to healthier and more productive growth.

Part of the nutrients absorbed by trees during a vegetative season returns to the soil through fallen leaves, pruning wood or root death potentially could be available again for uptake. It is also important to highlight that proper pruning allows for better sunlight penetration and air circulation that can enhance photosynthesis, which in turn can impact the tree's ability to absorb and utilize nutrients effectively.

The nutritional content of apples primarily includes:

- Vitamins –source of vitamin C and B.
- Minerals - potassium (K) and smaller amounts of other minerals.
- Fiber - apples are known for their dietary fiber content, particularly in the skin.
- Water - high-water content.
- Calories: 95 calories in a medium-sized apple

According to GrowingFruit.org the most important nutrient is nitrogen (N). Young trees require about 0.1 pounds of actual nitrogen per year of age. Mature trees need 0.1 to 0.2 pounds of nitrogen per inch of trunk diameter measured at knee height. Phosphorus (P) and Potassium (K) are usually applied based on soil test results. In terms of the application, fertilizers are typically applied in early spring and again in early summer. Nutrients contained in fruits leave the ecosystem and often have to be replaced by fertilizers. Nutrients stored above and belowground in tree framework can also be considered as losses as they leave the system when trees are removed. Regular soil testing is recommended to tailor the fertilization needs accurately[12].

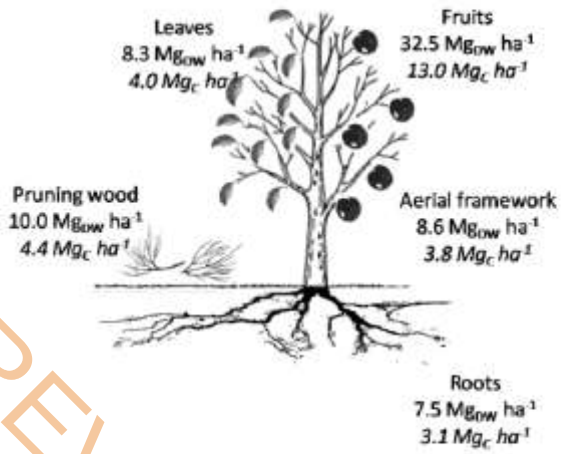
According to Scandellari[13], six year-old excavated trees had a total biomass 16.1 ± 0.8 Mg $ha^{-1}$, corresponding to 6.9 ± 0.4 Mg C $ha^{-1}$. The biomass of excavated trees was distributed 17% to branches and twigs, 26% to above grafting stem, 10% to below grafting stem, 32% to coarse roots and 15% to

[12] growingfruit.org/t/fertilizing-fruit-trees/15376

[13] Scandellari, F., Ventura, M., Malaguti, D., Ceccon, C., Menarbin, G. and Tagliavini, M. (2010). *Net primary productivity and partitioning of absorbed nutrients in field-grown apple trees*. Acta Hortic. 868, 115-122, DOI: 10.17660/ActaHortic.2010.868.11

fine roots. Integrating biomass data relative to tree excavation and those reported in Table 1 we could estimate a cumulative (years 1-6) value of NPP of 67 Mg (in term of biomass) and 28 Mg (in term of C) (Scandellari et al, 2010).

Figure 14. Nutrients in apple trees




*Source: Scandellari et al, Net primary productivity and partitioning of absorbed nutrients in field-grown apple trees, (2010)*

Excessive or insufficient fertilizer addition in orchards affects growth, fruit yieldand quality or represents a source of environmental pollution. Under sustainable agriculture it is therefore necessary to determine the amounts of nutrients.

### 1.1.6. Nutrient availability – apple pomace

Apple pomace is a heterogeneous mixture consisting mainly of skin and flesh (95%), with a tiny proportion of seeds (2%–4%) and stems (1%). Apple pomace is a rich source of nutrients and phytochemicals, such as carbohydrates, vitamins and minerals. It consists of a high amount of carbohydrates, of which about 70% are simple sugars, have a high source of arabinose and rhamnose and contain from 10 to 12% glucose (dry weight basis), which is amain fuel source for most tissues throughout human body. Besides carbohydrates, apple pomace is also a source of proteins.

Apple pomace is a rich source of many minerals, which are of interest from the human nutritional point of view. Potassium represents the main portion of the total mineral content of apple pomace and provides 20% of Recommended Dietary Allowances (RDA) after consumption of 100g of apple pomace. Sodium and phosphorus are the next most widespread minerals in apple pomace and provides respectively 13% and 11% of RDA.

Apple pomace is also a rich source of copper and zinc, both of which are essential for human well-being.

Figure 15. Proximate nutritious composition of apple pomace

| Constituents | Composition (dry weight basis) | Constituents | Composition (dry weight basis) |
|---|---|---|---|
| Moisture (%) | 3.90–10.80 | **Alcohol-soluble fraction of carbohydrate** | |
| Protein (%) | 2.94–5.67 | Saccharose (%) | 3.80–5.80 |
| Total carbohydrate (%) | 48.0–62.0 | Glucose (%) | 19.50–19.70 |
| Fibre (%) | 4.70–51.10 | Fructose (%) | 48.30 |
| Insoluble fibre | 36.50 | Xylose, mannose and galactose (%) | 1.20–4.40 |
| Soluble fibre | 14.60 | L-malic acid (%) | 2.60–3.20 |
| Fat (ether extract, %) | 1.20–3.90 | Arabinose and rhamnose (%) | 7.90–6.0 |
| Pectin (%) | 3.50–14.32 | Glucooligosaccharides (%) | 3.40–3.80 |
| Ash (%) | 0.50–6.10 | Xylooligosaccharides (%) | 3.0–3.70 |
| **Minerals** | | Arabinooligosaccharides (%) | 0.20–0.40 |
| Phosphorus (%) | 0.07–0.076 | Uronic acid (%) | 2.70–3.40 |
| Potassium (%) | 0.43–0.95 | **Alcohol-insoluble fraction of carbohydrate** | |
| Calcium (%) | 0.06–0.10 | Glucan (%) | 41.90–42.90 |
| Sodium (%) | 0.20 | Starch (%) | 14.40–17.10 |
| Magnesium (%) | 0.02–0.36 | Cellulose (%) | 7.20–43.60 |
| Copper (mg/kg) | 1.10 | Polysaccharides of xylose, mannose and galactose (%) | 13.0–13.90 |
| Zinc (mg/kg) | 15.00 | Polysaccharide of arabinose and rhamnose (%) | 8.10–9.0 |
| Manganese (mg/kg) | 3.96–9.00 | Acid detergent lignin (%) | 15.20–20.40 |
| Iron (mg/kg) | 31.80–38.30 | Uronic acid (%) | 15.30 |

Source: Bhushan, et al., 2000



The variation of chemical profiling among apple pomace is controlled by variable factors viz. origin, variety, as well as type of processing. Apple pomace as a part of apple contain significant amounts of polyphenols. The apple pomace is big source of flavonoids (flavanols and flavanols), which consist of quercetin 3-O- rutinoside, quercetin 3-O-galactoside, quercetin 3-O-glucoside, quercetin 3-O-xyloside, quercetin 3-O-arabinoside and quercetin 3-O-rhamnosid. Apple pomace contains about 5% of seeds, which contain from 27.5 to 28% lipids, and could be a good source of oil. The oil from apple seeds can be obtained by cold-pressing or hot-extracting. Additionally apple seeds oil contains high levels of linoleic acid (49%) and other dominant fatty acids as oleic, palmitic and stearic acid.

Apple pomace contains many pro-health compounds, including bioactive phenolic compounds with antioxidant and anti-inflammation properties. It has great potential for conversing into edible products, as it is characterized by a high content of pro-health compounds like dietary fibre and many phytochemicals, including phenolics, like quercetin, catechin, phloretin/ phlorizin, gallic acid and chlorogenic acid, all of them can reduce chronic disease risk. Therefore apple pomace can be a potential source for health food preparations. Dry apple pomace is a natural concentrate of bioactive substances from the group of polyphenols.

In terms of innovative applications of nutrients, apple pomace could be incorporated into bakery products, meat products, confectionery and dairy products. It could enhance their nutritional value or act as a flavouring or stabilizing agent. The most common application of apple pomace in the food industry resides in their high antioxidant ingredients that are added as preservatives in addition to their redox properties that prevent many chronic diseases associated with oxidative stress. In terms of fresh apple pomace, it has high moisture content and is often susceptible to microbial degradation marketed often, therefore needs to be dehydrated during drying and then ground into powder.

## 1.4 Discussion of the Results

Apple trees require yearly prunings, which leaves a substantial amount of residues. This woody biomass could be a promising source of raw materials in the wood industry and could replace traditional wood assortments for bioenergy and industrial uses. Additionally, nutrients from the prunings could also be returned to the soil, by chipping the prunings and using it as a fertilizer. Due to their significant energy balance, it is also an economically justified source of energy for the local market because of its reasonable productivity, good energy balance, and positive economic outcomes. However, alternative paths of apple pruning valorization should be considered and further researched.

The apple juice production process results in solid residues, also known as apple pomace. This apple pomace is a rich source of nutrients, carbohydrates, vitamins and minerals. Due to its high content of biologically active components valuable for human and animal nutrition, it could be used as a functional ingredient in many types of food and feed. However, the pomace also has a high water content and a tendency to rot quickly, so it is important to treat it as soon as possible to mitigate the risk of biological contamination. These potential applications and the best course of action should be further researched.

## 1.5 Conclusions and Recommendations

### 1.1.7. Conclusions

In this report the availability of apple tree prunings and apple pomace has been analysed. These are important biomass resources in the Mazovia region. Mazovia is the largest apple producing region, good for almost half of the Polish production. Poland is the largest apple growing country in the EU.

**Prunings**

Annual pruning is required for the proper growth of the apple tree and for ensuring high apple production. Pruning generates woody residues with branches and leaves, which must be disposed of. In Mazovia, the theoretical potential is estimated at 50.000 ton (dry) per year. The technical availability will be close to that figure as collection is mostly well to organise in the field. Most prunings are currently baled and collected to serve as fuel for heating in wood boilers. Economic availability depends on fuel prices and costs of collection. Wood prices have been good the last few years, but costs depend highly on local orchard management and transport costs.

**Apple pomace**

Apple pomace is the left-over solid residue resulting from extraction of juice. In Mazovia, the theoretical potential is estimated at almost 250.000 ton (fresh) or some 150.000 ton (dry) per year. The technical availability will be close to that figure as the waste stream comes available in the factory where it can be easily collected. Most apple pomace are currently used as animal feed. Price ranges from 430 – 550 euro per ton (fresh material). New applications of apple pomace are being developed as part of this project. Several new products are mentioned in this report. Quality of the feedstock and biological contamination may be an issue for some high value applications.

Figure 16, apple biomass potential in Mazovia

| Geographical area | production area | production rate | apple production | prunings | pomace |
|---|---|---|---|---|---|
| | ha | ton/ha/year | kton/year | kton/year (dry) | kton/year (dry) |
| Poland | 161.948 | 25,12 | 4.068 | 112 | 305 |
| Mazovia | 69.816 | 28,21 | 1.970 | 48 | 148 |
| | | | | | |
| **Conversion factors** | | | | | |
| Prunings | 0,69 | t(dm)/ha/year | | | |
| Apples processed | 50% | | | | |
| Pomace/processed apple | 25% | | | | |
| Pomace moisture content | 40% | | | | |

**Nutrients**

For sustainable apple production good soil and proper nutrition is essential. Nitrogen (N) is important. Young trees require some 50-gram nitrogen per year of age. Phosphorus (P) and Potassium (K) are usually applied based on soil test results. Fertilisers are typically applied in early spring and again in early summer.

There should be potential for using biomass residues for nutrient recycling and soil improvement, but it is unclear how much this potential is already used in the region.

### 1.1.8. Recommendations

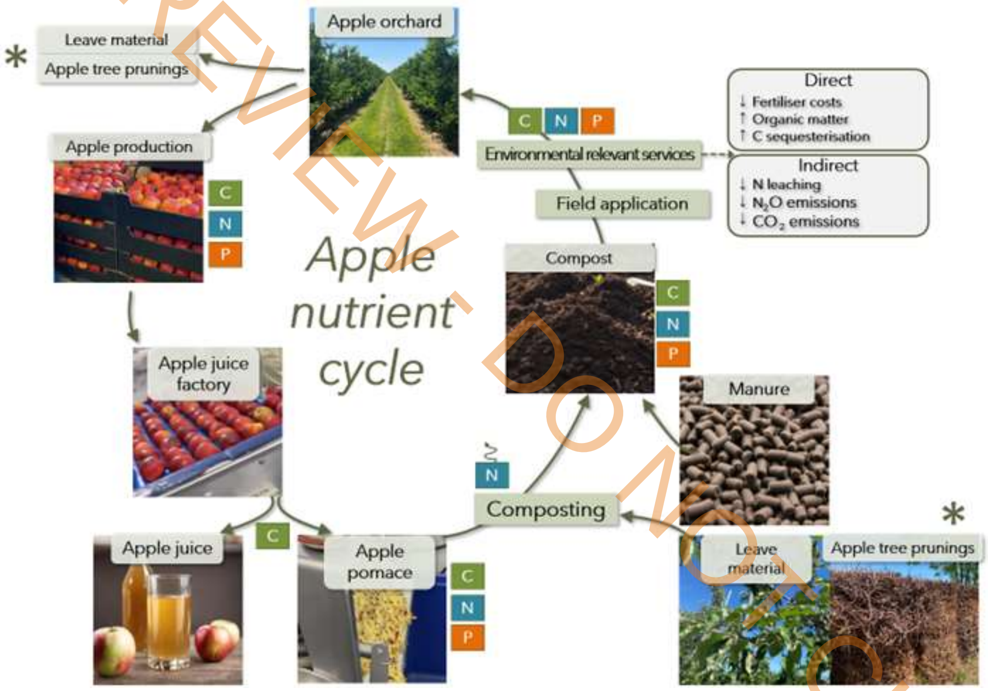
**Biomass availability**

- Share experience - within the Mazovia platform - in prunings collection, processing and storage systems.
- Share experience in apple pomace collection, processing and feed stock quality assurance for high value applications.
- Support the development of storage and production systems close to agricultural production, which will reduce production and storage costs, reduce the risk associated with the seasonality of production and have a positive impact on the local economy. This requires the involvement of public funds and attracting private investors.

**Nutrients**

- Develop and share know-how on the production of compost from prunings with a mix of organic streams and the application of compost for nutrient supply and soil improvement for orchards. Assess the potential of nutrient recycling systems as shown in the following diagram.

Figure 17, Apple nutrient cycle, own image.






**General**

- Develop a bioresources regional strategy with proper support instruments for biobased production.
- Support cooperation between stakeholders (science, local government and entrepreneurs) to share experience and know-how and stimulate joint development on biomass production, nutrient recycling, biomass processing with high value products. Promote technical and business development.