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1. State of the art: market conditions of CSS1

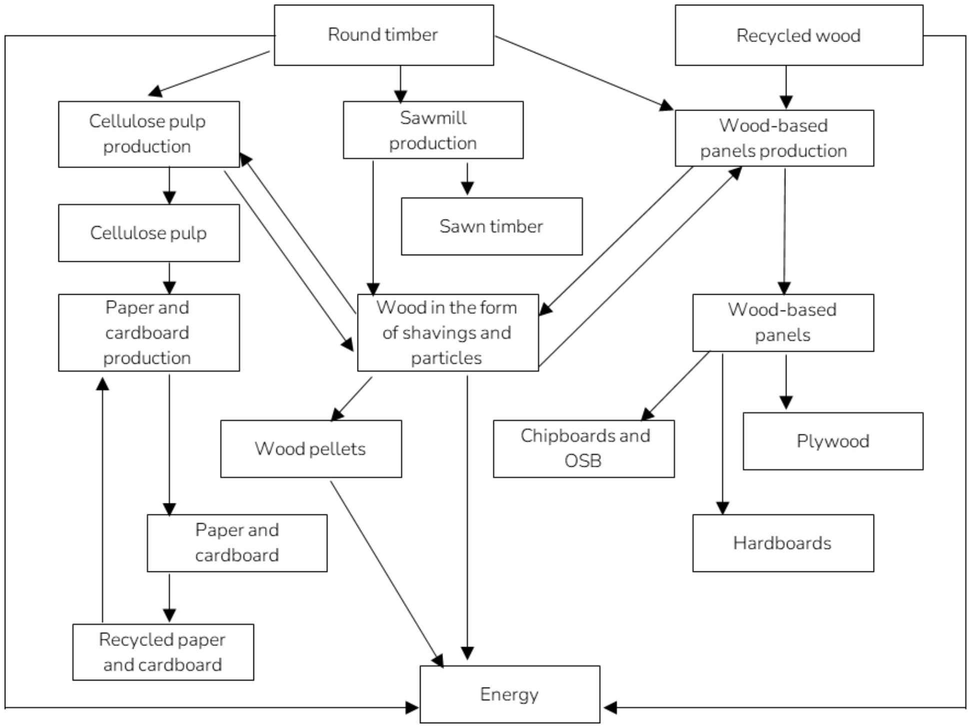
This section is dedicated to the definition of the state of the art of *CSS1 – Wood packaging waste*. The analysis covers both the technical and non-technical aspects of the circular systemic solution. It focuses not only on CSS1 value chain, but also on wood waste and residual biomass valorization strategies, bioenergy production and wood market considering both the national and regional level.

1.1 Market Analysis of Circular Regional Cluster

1.1.1 Circular Value Chain Characteristics

Wood is a very valuable and strategic raw material, considering its functions and possibilities of use. Therefore, the management of this raw material for energy purposes should not be a priority course of action. In Poland, raw wood is used in the sawmill industry and for the production of wood-based panels, as well as in the paper industry, the furniture industry, and in the construction industry. The production of wood-based panels employs 46% of raw wood and 46% of by-products of the sawmill industry, such as shavings and sawdust, as well as 4% of recycled wood (https://www.pkobp.pl/ [access: 03.08.2022]). The formation and use as well as a conceptual material flow of wood raw material are shown in Diagram 1.

Diagram 1: The formation and use as well as the simplified flow of wood raw material



Source: own study.

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Forests are the main source of raw wood. In Poland, the forest area covers 9,259 thousand ha, of which 7,472 thousand ha are state forests. In total, forests cover 30.9% of Polish territories, with a forest cover index of 29.6%. In lodzkie voivodeship, there are 392 thousand ha of forests, corresponding to 22% of the voivodeship area, with a forest cover index of 21.4%. Consequently, lodzkie voivodeship sits in the last position countrywide relatively to its forest area. The best positioned regions in the rank are instead lubuskie voivodeship (with a forest cover index of 49.3%), podkarpackie voivodeship (38.2%) and pomorskie voivodeship (36.4%) (GUS, 2021a, p. 37).

Table 1: Acquisition of wood – **large timber** in 2020 [thousand m^3]

Specification	**Poland**	**Lodzkie voivodeship**
Total	38069.2	1353.4
Large coniferous timber in total	29615.9	1104.1
of which		
Large-size general purpose wood	13902.2	541.9
Large-size special wood	122.6	0.8
Medium-size wood for industrial uses	14053.9	496.8
Fuel-wood	1375.0	55.3
Large non-coniferous timber in total	8453.3	249.3
of which		
Large-size general purpose wood	2336.5	57.7
Large-size special wood	206.3	2.3
Medium-size wood for industrial uses	4288.4	126
Fuel-wood	1621.9	63.3

Source: GUS, 2021a.

In 2020, a total of 39,674 thousand m^3 of wood were obtained in Poland, including large timber (38,069.2 thousand m^3), slash (1,604 thousand m^3) and stump wood (4.4 thousand m^3). The majority of slash was intended for use as fuel (1,437 thousand m^3), while the remaining part was intended for industrial uses (167 thousand m^3). In lodzkie voivodeship, 1,353.4 thousand m^3 of large timber was obtained in total, which corresponds to the 3.5% of the national production. Lodzkie voivodeship is in the 12th place among all the sixteen voivodeships in terms of harvested wood. This corresponded to a harvest rate of 346.9 m^3 / 100 ha of forest area, which indicates the volume of large timber harvested per 100 ha of forest areas. The highest harvest rate was found in dolnoslaskie voivodeship, at 544.8 m^3/ 100 ha of forests. Overall, in 2020, the pre-final felling[1] area in state-owned forests consisted of 354.4 thousand ha area of fellings, from which 16,594 thousand m^3 of large timber was acquired, of which 3,469 thousand m^3 was deadwood, windbroken and

[1] Pre-final (pre-commercial, intermediate) felling/cutting – harvesting of immature trees from the forest to improve the quality of the remaining forest stand associated with stand tending.

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windthrown trees. Thinnings, on the other hand, amounted to 13,920 thousand m^3. A total of 894.7 thousand m^3 and 94.6 thousand m^3 were acquired from trees and shrubs outside the forest nationwide, and in lodzkie voivodeship, respectively (Table 2).

Table 2: Acquisition of wood from trees and shrubs outside the forest in 2020 [m^3]

Specification	Poland	Lodzkie voivodeship
Large timber total	894,732	94,635
Large coniferous timber	282,632	31,354
Large non-coniferous timber	612,100	63,281

Source: GUS, 2021a.

1.1.2 Waste and residues from the wood value chain in the lodzkie voivodship and in Poland

From the perspective of the sustainable use of raw wood through a circular economy approach, it is important to properly manage the wood waste generated at each stage of the value chain. The classification of wood waste varies depending on the adopted subdivision criterion. There are three main groups of wood waste. The first one is **waste from forest management**, such as residues from maintenance works. The second group is **wood waste from industry** (generated in the production process of the final goods). Industrial wood waste is generated in the production of goods from wood raw material and can be in the form of particles, shavings, sawdust, wood dust, wood chips or bark. The amount of industrial waste can be estimated on data based on the material efficiency of individual production technologies. According to the literature, the wood processing efficiency in sawmills is 60%, in the production of plywood it is 35-60%, and in the production of chipboards and hardboards it is over 90% (Kurowska 2016, p. 187-196). Therefore, waste from sawmill production accounts for 60-70% of industrial wood waste. The third group of waste is **post-consumer waste** (from the consumption of the final goods). This is the most diverse group. This group of waste includes, among others, wood from demolition, furniture, windows and doors, packaging, e.g., pallets or paneling and flooring (Kurowska 2016, p. 187-196). By adopting a different nomenclature, a distinction can be made between usable waste, considered as secondary raw material, and non-usable waste. According to the type of wood raw material, we can distinguish between solid wood waste (round or processed) and waste from other wood-based materials (plywoods, chipboards, hardboards, blockboards).

Based on the available OECD data, in 2018, 175,144 thousand tons of waste (Total amounts of waste generated by sector) were generated by different sectors in Poland. The total amount of primary waste generated was 160,463 thousand tons, including 14,681 thousand tons (9.15%) of segregated waste. In addition, this group includes waste from agriculture,

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forestry, and aquaculture in the amount of 426 thousand tons (0.3%), and 29,281 thousand tons (18.25%) were waste from industrial sectors. Waste from the production of paper and paper products amounted to 1,087 thousand tons, (3.7%), and waste from the production of wood and wood and cork products, except for the production of furniture, the production of straw articles and plaiting materials accounted for 1,175 thousand tons (4%). Construction waste amounted to 16,778 thousand tons, representing 10.45% of total generated primary waste (https://stats.oecd.org [access: 03.08.2022]).

In 2020, 109,466 thousand tons of industrial waste were generated in Poland overall, 23,123 thousand tons of which came from industrial processing. A significant part of industrial waste, i.e., 60,838 thousand tons, was waste from mining and quarrying. In the sector dealing with the production and supply of electricity, gas, steam, and hot water, 11,591 thousand tons of waste were generated, while the construction sector generated 7,352 thousand tons of waste. In the lodzkie voivodeship, waste from energy generation through thermal processes was dominant, whereas waste from wood processing and from the production of wood-based panels and furniture, cellulosic pulp, paper, and cardboard dominated in lubuskie voivodeship (GUS, 2021b, pp. 152-155).

Table 3: The amount of industrial waste generated in lodzkie voivodeship divided by counties in 2020 [thousand tons]

Specification	**Total**	**Recycled**
Poland	109,466	25,986.7
Lodzkie voivodeship	7,191.7	309.8
Belchatowski County	6,022.6	23.2
Kutnowski County	98	11.4
Laski County	1.1	0.5
Lowicki County	13.9	0
Lodzki Wschodni County	2.5	0
Pabianicki County	12.8	3.9
Piotrkowski County	74.4	74.4
Poddebicki County	28.6	0
Radomszczanski County	73.2	0
Rawski County	1.8	0
Skierniewicki County	18.5	0
Tomaszowski County	383.1	153.1
Wielunski County	19	0
Wieruszowski County	19	2.2
Zdunskowolski County	15	0

Source: BDL, GUS [access: 05.08.2022].

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1.1.3 Valorization of wood waste and residues in the Polish context

Recycling of wood waste can lead to the production of fuel, woody charcoal, particle boards and hardboards, new wooden packaging such as pallets or crates, bark used in gardening or sawdust used as animal bedding. On the other hand, when properly processed, it can be transformed into cellulose pulp needed for paper products manufacturing (https://www.ebrodnica.pl, [access: 05.08.2022]. On the other hand, wooden waste such as crates, pallets, old wooden or wood-based furniture could be difficult to manage due to its large dimensions, and thus the need for a large storage space. In addition, inadequate storage is a big problem in terms of fire safety. Wood waste can be upcycled, i.e., using pallets or crates for the production of modern furniture used in bars, restaurants and homes. Pallet type waste can be repaired as long as no more than three elements are damaged. In addition, recycling of wood-based products enables the production of particle boards and OSB, pressing sawdust under pressure, and the production of materials for finishing terraces, such as composite floorboards. Wood waste can be used for energy purposes, but prior to that it must be processed into fuel (https://zeme.com.pl, [access: 05.08.2022]).

Pallets and other transport packaging materials are a special type of wood waste. It is possible to run a collection point for wood waste such as pallets, by obtaining a special permit, as well as a permit for the use of a building object (Regulation of the Minister of the Environment from September 27th, 2001 on the waste catalogue) (http://www.presseko.pl, [access: 05.08.2022]). Pursuant to the Act from June 13th, 2013, on the packaging management and packaging waste, the operator must meet the minimum levels of recovery and recycling of packaging in a given year. Moreover, such an operator is obliged to issue a KPO document if they transfer the waste further to the site of storage, processing or to another holder. In addition, it is required to have a DPR (document confirming the method of recycling a specific mass of waste) and DPO (a document confirming the method of packaging waste recovery other than recycling along with the given weight and method of waste recovery).

Research conducted by the Wood Technology Institute shows that about 7.5 - 8.1 million m^3 of industrial wood waste is generated in Poland, which constitutes 27% of the total wood raw material. Additionally, about 4.5 - 4.9 million m^3 is generated in the sawmill industry. Most of this waste, i.e., 63%, is generated in sawmill operations. However, 14% comes from the furniture industry, and 13% from the production of wood-based panels. It should be emphasized that the research shows that 87% (about 6.4 million m^3) of industrial wood waste in Poland is recycled in wood-based panels or used for energy purposes (https://www.drewno.pl, [access: 03.08.2022]).

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1.1.4 Energy production as a market for residual biomass

1.1.4.1 Energy generation in Poland

In the context of the EU climate and energy policy, the energy sector is closely related to the availability of raw wood in the Polish economy, both in terms of virgin materials and wood waste. Relatively to the production of electricity and heat, the energy sector in Poland is based mainly on conventional fuels, especially hard coal. In 2020, 157.1 TWh of electricity and 441.1 PJ of heat were used in Poland. Overall, 62.4 million tons of coal were used, of which 59.2% was used by the energy sector, 3.7% by industry and construction, and 13.9% by households.

In terms of regions, the highest consumption was recorded in slaskie, mazowieckie and opolskie voivodeships. Natural gas consumption was 694.7 PJ, with the highest level in mazowieckie voivodeship. In lodzkie voivodeship, electricity consumption accounted for 8% of domestic consumption (GUS, 2021c).

Table 4: Consumption of selected energy carriers in lodzkie voivodeship in 2020

Specification	Hard coal [thousand tons]	Natural gas [TJ]	Liquified petroleum gas (excluding vehicles) [thousand tons]	Light fuel oil [thousand tons]	Heavy fuel oil [thousand tons]	Consumption of heat [TJ]	Consumption of electricity [GWh]
Total consumption	2,107	22,359	57	44	16	18,743	12,204
Energy sector	1,079	573	N/A	4	14	N/A	4,571
Industry and construction	167	13,038	3	7	1	4,155	2,374
Transport	1	19	N/A	0	N/A	99	588
Small consumers sector	860	8,729	54	22	1	14,489	4,672

Source: https://stat.gov.pl, [access: 06.08.2022].

Energy production from RES (Renewable Energy Sources) in Poland reached 28,226.6 GWh, which accounted for 17.9% of the total production. In lodzkie voivodeship alone, 1,827.4 GWh of energy was produced from RES (6% of the total domestic production). Solid biofuels (72%) occupy the largest share in the primary energy mix derived from RES, while other renewable provide much lower contributions, with wind energy at 11%, liquid biofuels at 8%, biogas at 3%, heat pumps at 2%, solar energy at 2%, hydropower at 1%, and municipal waste at 1% (Figure 1).

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Figure 1: The structure of obtaining primary energy from renewable sources in Poland in 2020

Source: GUS 2022, p. 13.

In 2020, biomass-fired power plants and CHP (Combined Heat and Power) plants produced a total of 3,195.3 GWh of energy, of which 2,804 GWh was fed into the grid. There are four commercial biomass-fired power plants in Poland: Polaniec - Zielony Blok, Konin KONG, Jaworzno 2 - BM, Stalowa Wola - BM. The total installed capacity of these power plants was 385 MW and they produced a total of 2,323 GWh in 2020. The largest plant is the Polaniec power plant with a capacity of 230 MW, and a gross production of 1,559.1 GWh. Konin Power Plant with an installed capacity of 50 MW produced 368.7 GWh of gross energy, whereas Jaworzno (50 MW) and Stalowa Wola (55 MW) generated 294.1 GWh, 101 GWh, respectively (ARE, 2021).

Table 5: List of biomass power plants in Poland

Power plants	**Installed capacity [MW]**	**Gross energy production [GWh]**
Połaniec – Zielony Blok	230	1,559.1
Konin KONG, ,	50	368.7
Jaworzno 2 – BM	50	294.1
Stalowa Wola – BM	55	101
CHP plants of installed capacity between 50 and 99 MW		
Ec. Szczecin	76	332.4
CHP plants of installed capacity up to 49 MW		
Ec. Łódź 4 – BM	59	258.7
Ec. Tychy – BM	40	175.8
Ec. Elbląg – BM	25	43.7
Ec. Kielce – BM	6.7	38
Independent CHP plants		
Stelmet Bioenergia Spółka z o.o. Spółka Jawna	1.6	6.3
CHP plants owned by Heat Enterprises		
PEC Płońsk Sp. z o.o.	2.2	7.6
MPEC Sp. z o.o. Lębork	1.4	9.7

Source: ARE, 2021, pp.83-88.

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In Poland, in 2020, a total of 402,560 TJ of energy derived from solid biofuels. Of that, 11,911 TJ were exported, and 27,244 TJ were imported. Eventually, 311,773 TJ of energy from solid biofuels was used.

Table 6: Energy balance from solid biofuels in Poland in 2018-2020 [TJ]

Specification	2018	2019	2020
Domestic Production	384,914	377,057	375,316
Import	21,934	30,011	27,244
Export	13,546	13,768	11,911
Total Domestic Consumption	393,302	393,300	390,649
Final Energy Consumption	334,785	322,079	311,773

Source: GUS, 2022, Warszawa, p. 74.

Considering production activities only, such as iron and steel, non-metallic mineral and transport industries, machinery, food, beverages and tobacco, paper, pulp and printing, wood and other industries, a total of 81,015 TJ of energy from solid biofuels was consumed in 2020. The greatest demand came from the paper and printing sector (40,403 TJ), as well as the wood sector (34,745 TJ). On the other hand, households consumed 203,228 TJ of energy derived from this carrier.

Table 7: Final energy consumption from solid biofuels in Poland by sector in 2018-2020 [TJ]

Specification	2018	2019	2020
Iron and steel	1	1	N/A
Non-metallic minerals	216	208	295
Transport equipment	2	N/A	28
Machinery	51	64	61
Food, Beverages and Tobacco	1,244	780	650
Paper, Pulp and Printing	36,138	38,625	40,403
Wood and Wood Products	26,746	30,685	34,745
Non-specified industry	4,403	5,046	4,833
Construction	21	22	11
Transport	N/A	N/A	N/A
Commerce and Public Services	7,556	7,307	7,451
Households	237,671	219,724	203,228
Agriculture/Forestry	20,735	19,618	20,068

Source: GUS, 2022, p. 74.

In 2020, there were 171 commercial thermal power plants, 6 commercial hydroelectric power plants, 127 wind farm companies, 126 industrial CHP plants. In Poland, in 2020, the installed electrical capacity reached 51,792.7 MW, including 8,977.9 MW of independent renewable power plants. In lodzkie voivodeship alone, the installed capacity was 6,654.8 MW, including 788.7 MW of independent renewable power plants, which accounted for 11.8% of the voivodeship share, and 8.8% for the country. There is an increase in installed

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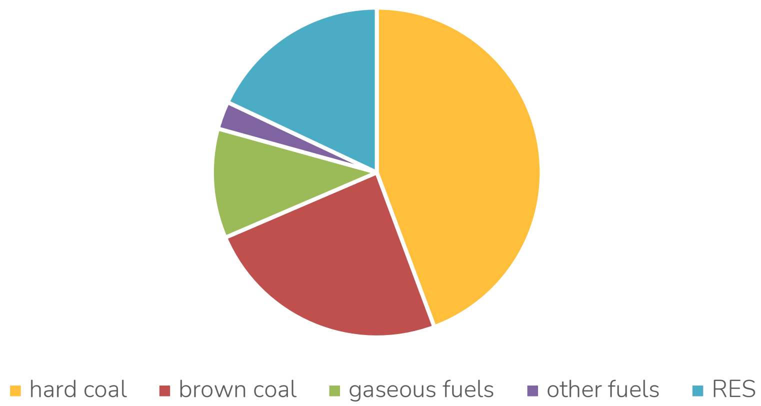
capacity from independent renewable power plants amounting to 157 MW during that year in lodzkie voivodeship. The voivodships with the highest achievable electric capacity from RES were zachodniopomorskie, pomorskie, kujawsko-pomorskie and wielkopolskie voivodeships (ARE, 2021).

In 2020, a total of 158,043 GWh of electricity was produced, 126,650 GWh of which came from the power generation sector, 14,719 GWh from renewable independent power plants and 16,674 GWh from industrial power plants (ARE, 2021, p. 22). Hard coal covered the largest share in the electricity production structure - 44.1%. RES accounted for 17.9% of the total. Wind energy covered the largest share in electricity production among all the RES (10%). Biomass occupied the second share (4.5%) and was followed by hydropower (1.3%), solar energy (1.2%) and biogas (0.8%) (ARE, 2021) (Figure 2).

Figure 2: The structure of electricity production in Poland in 2020



Source: ARE, 2021.

A total of 158,042.7 GWh of gross electricity was produced in Poland, 14,719.3 GWh of which from independent renewable power plants (ARE, 2021, p. 111). Lodzkie voivodeship produced the greatest share of gross electricity (30,563 GWh) nationwide, considering all fuel types. The total local production accounted for 19.3% of the total gross electricity generated in the country. Right behind the lodzkie voivodeship, mazowieckie generated 30,365.5 GWh (ARE, 2021, p. 111). In the lodzkie voivodeship, gross electricity generated by independent renewable power plants was 1,328.8 GWh. Table 8, below, presents the available data from the database of the Central Statistical Office of Poland – GUS BDL, showing the sources of electricity production in individual voivodeships.

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Table 8: Electricity production by sources in 2020 [GWh]

Specification	Total	RES Water Power Plants	Water Power Plants	Total Conventional CHP Plants	Professional Conventional CHP Plants	Industrial Conventional CHP Plants	RES CHP Plants
Poland	158,042.7	21,346	2,937	136,696.7	120,026.5	16,670.2	28,226.6
dolnoslaskie	8,706.2	818.4	200.3	0	0	0	885.1
kujawsko-pomorskie	8,134.1	2,435.3	0	0	0	0	3,694
lubelskie	2,723.8	551.7	0	0	0	0	597.3
lubuskie	3,387.5	752.3	123.1	0	0	0	762.3
lodzkie	30,563	1,527.5	0	0	0	0	1,827.4
malopolskie	4,790.4	540	0	0	0	0	697.5
mazowieckie	30,365.5	1,382.6	0	0	0	0	1,984.1
opolskie	13,532.7	534.5	133.6	0	0	0	549.2
podkarpackie	3,410.1	669.6	0	0	0	0	783.8
podlaskie	1,312.1	682.9	2.7	0	0	0	1,047.5
pomorskie	5,177.3	2,865.6	0	0	0	0	2,928.8
slaskie	19,856.7	633.6	0	0	0	0	1,469.4
swietokrzyskie	7,127.1	127	7.2	0	0	0	2,112.9
warminsko-mazurskie	1,485.8	1,202.8	32.4	0	0	0	1,294
wielkopolskie	8,962	2,063.9	42.2	6,898.1	6,576.7	321.4	2,619.6
zachodniopomorskie	8,508.4	4,558.3	96	0	0	0	4,973.7

Source: BDL, GUS [access: 06.08.2022].

Gross electricity production from RES from all power plants in Poland amounted to 28,226.56 GWh in 2020. Lodzkie voivodeship was ranked seventh with a production of 1,827.37 GWh (which accounts for 6% of the total electricity produced in the region). Higher ranks were occupied by the following voivodeships: zachodniopomorskie (4973.73 GWh), kujawsko-pomorskie (3694.01 GWh), pomorskie (2928.76 GWh), wielkopolskie (2619.55 GWh), swietokrzyskie (2112.90 GWh), mazowieckie (1984.14 GWh) (ARE, 2021, p. 111). The largest share of production in the country was held by wind farms (56%) and biomass power plants (17%). Co-combustion of biomass with coal accounted for 7% of the total (ARE, 2021, p. 111).

Considering independent, decentralized power plants, gross electricity production amounted to 14,719.28 GWh nationwide. The largest share was held by wind farms (11,812.35 GWh) and photovoltaic power plants (1,957.92 GWh). This was followed by biogas power plants (645.77 GWh), hydropower plants (295.56 GWh), and biomass power plants (7.68 GWh). It should be emphasized that on a national scale, there is a decrease in gross electricity production from biomass in decentralized power plants from 12.15 GWh in 2019 to 7.68 GWh in 2020. However, considering commercial power plants, gross electricity production from biomass increased from 4,642.84 GWh in 2019 to 4,889.27 GWh in 2020. Considering the co-combustion of biogas and biomass, the situation is similar. There was an increase in this case from 1,528.41 GWh in 2019 to 1,926.95 GWh in 2020 (ARE, 2021, p. 111).

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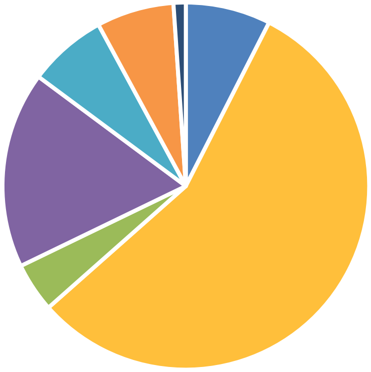
Figure 3: The structure of gross electricity production from RES in Poland in 2020



Source: ARE, 2021.

In 2020, the most biomass and biogas were used in industrial CHP plants generating electricity for the production of paper and paper products (11,072.7 TJ). In other sectors, biomass and biogas were used to a lesser extent, e.g., in activities related to the collection, processing, disposal of waste and recovery of raw materials, 1617.6 TJ were used (code 38 PKD 2007), in the discharge and treatment of sewage (794 TJ, code 37 PKD 2007), in the production of chemicals and chemical products (350.8 TJ, code 20 PKD 2007), in the production of food products (180.1 TJ, code 10 PKD 2007) (ARE, 2021, p. 106).

Taking into account the gross electricity production from independent renewable power plants, the highest share was produced by the following voivodeships: zachodniopomorskie (2549.6 GWh), wielkopolskie (1950.9 GWh), kujawsko-pomorskie (1629.1 GWh), pomorskie (1459.3 GWh), lodzkie (1,328.8 GWh). In total, 14,719.3 GWh of gross electricity was produced in Poland from independent renewable power plants in 2020 (ARE, 2021, p. 106).

Table 9: List of prosumer power plants in Poland in 2020

Specification		**Total**	**of which**					
			Hydro Power Plants	**Wind power plants**	**Photovoltaic power plants**	**Hybrid systems**	**Biogas power plants**	**Biomass power plants**
Number of units	2019	144,940	8	56	144,856	17	3	N/A
	2020	435,455	18	67	435,314	29	10	17
Installed capacity [MW]	2019	827.61	0.09	0.19	827.08	0.16	0.09	N/A
	2020	2,731.76	0.25	0.6	2,730.67	0.27	0.17	0.14
Electricity fed into the OSD grid [MWh]	2019	307,406.5	59.89	43.16	307,221.97	78.30	3.18	N/A
	2020	1,069,530.42	331.05	84.7	1,068,832.33	153.53	117.22	11.58

Source: ARE, 2021.

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ARE report shows that the number of electricity prosumers increased from 144,940 to 435,455 in years 2019-2020. This increase is due to the significant development of photovoltaic power plants, which in 2020 reached the number of 435,314 units with a total installed capacity of 2,730.67 MW and electricity production fed into the grid at 1,068,832.33 MWh.

There were 17 prosumer biomass power plants with installed capacity of 0.14 MW and electricity production of 11.58 MWh (ARE, 2021).

In Poland, heating plants with an installed capacity of 10-50 MW predominate and constitute 44.6% of the total followed by plants with a capacity of 50-125 MW (19.8%) and 10 MW and below (8.3%). The share of heat from cogeneration was 65.2% of the total heat production. A decrease in the share of coal in the production of heat is visible. In 2002, they accounted for 81.7% of all fuels used for production, instead in 2020, for 68.9% (Table 10). RES (mainly biomass and biogas) had a 10.1% share in the heat production structure, and gas fuels 10.6% in 2020. In cogeneration, the share of RES in the production structure was higher and amounted to 11.5%. Considering the structure of heat production in individual voivodeships, it can be assumed that it is diversified in terms of region, with the greatest differentiation being visible in mazowieckie voivodeship. In nine voivodeships (dolnoslaskie, swietokrzyskie, lodzkie, opolskie, malopolskie, lubelskie, warminsko-mazurskie, wielkopolskie, zachodniopomorskie), hard coal has over 80% share in heat production. In kujawsko-pomorskie, podlaskie and pomorskie voivodeships, a significant share of RES is visible. In lubuskie voivodeship, 95% of heat is produced from natural gas (URE, 2022).

Table 10: Selected energy carriers for heat production by voivodeships in 2020

Specification	**Number of plants**	**Consumption**						
		Hard coal [thousand tons]	**Brown coal [thousand tons]**	**Heating oil [thousand tons]**	**Natural gas [mln m^3]**	**Biomass [TJ]**	**Biogas [TJ]**	**Other RES [TJ]**
Poland	370	12,758.7	579.1	499.4	1,345.9	41,548.4	175.4	721.5
dolnoslaskie	26	941.4	114.5	2.1	93.7	1,287.9	N/A	0.03
kujawsko-pomorskie	23	1,245.9	N/A	2.1	116.4	1,3825.7	21.8	N/A
lubelskie	16	866.8	N/A	0.7	100.8	1.9	N/A	0.7
lubuskie	6	11.6	3.1	0.1	276.8	30.4	N/A	N/A
lodzkie	26	837.6	424.4	2.6	13.3	2,454.5	N/A	62.6
malopolskie	24	1,019.9	N/A	2.5	37.3	319.9	N/A	573.9
mazowieckie	37	2,105.4	N/A	474.1	281.7	4,302.2	13.7	16.1
opolskie	13	399.1	N/A	73.1	41.7	2.2	N/A	N/A
podkarpackie	19	181.1	N/A	42.8	83	283.4	N/A	N/A
podlaskie	17	179.7	N/A	0.5	8.7	3,301.4	N/A	N/A
pomorskie	26	959.5	N/A	4.1	147.7	6,529.3	N/A	N/A

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slaskie	45	1,776.6	N/A	6.9	66.2	2,092.6	17.9	N/A
swietokrzyskie	15	334.3	N/A	0.03	4	658.1	N/A	N/A
warminsko-mazurskie	23	433.3	N/A	1	11.4	1,267.9	N/A	N/A
wielkopolskie	31	809.2	37.1	1.7	48.5	4,693.9	N/A	N/A
Zachodniopomorskie	23	657	N/A	0.3	14.7	497	N/A	68.2

Source: URE, 2022, p. 81.

In particular, we would like to draw attention on the **municipal boiler house in Parzeczew**, Poludniowa 7, administered by the Department of Municipal Economy in Parzeczew (https://www.zgkparzeczew.pl/infrastruktura/).

The boiler plant consists of three systems: a new biomass boiler plant, commissioned in December 2016, feeding one district heating unit with a capacity of 1.0 MW, a biomass boiler plant feeding two district heating units with a total capacity of 0.75 MW (peak boiler plant), and an oil boiler plant feeding two district heating units with a total capacity of 1.36 MW (emergency boiler plant).

The primary source in this system is a new biomass boiler plant. The oil-fired boiler plant system is only an emergency backup. The produced heat is supplied to consumers in the village of Parzeczew. At present, the heat consumers are:

- Julian Tuwim Elementary School,
- Municipal Office in Parzeczew,
- Health center in Parzeczew,
- Two multi-family buildings of the Housing Cooperative of Ozorkow located in Parzeczew,
- A multi-family, communal building in Parzeczew.

The total power demand is about 1.0 MW. The average annual heat production is about 5.0-5.5 thousand GJ.

1.1.4.2 Costs and prices of energy commodities

Heat prices in Poland amounted to an average of 44.33 PLN/GJ in 2020. The average price of heat sold from licensed heat producing sources without cogeneration was 51.87 PLN/GJ. On the other hand, the average price of heat sold from licensed heat producing sources with cogeneration was 41.32 PLN/GJ (https://www.ure.gov.pl, [access: 06.08.2022]). The lowest price was in mazowieckie voivodeship and amounted to 38.24 PLN/GJ, and the highest in opolskie voivodeship - 50.28 PLN/GJ. In lodzkie voivodeship, the price of heat was 45.45 PLN/GJ. In Poland heat from biomass cost 45.77 PLN/GJ, from hard coal 43.88 PLN/GJ, from light fuel oil 58.40 PLN/GJ, from high-methane natural gas 53.64 PLN/GJ, with the average equal to 44.33 PLN/GJ (URE, 2022).

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Table 11: Selected average unit costs of fuels used for heat production by voivodeships in 2020

Specification	Hard coal [PLN/ton]	Brown coal [PLN/ton]	High-methane natural gas [PLN/m^3]	Biomass [PLN/GJ]
Poland	302.91	52.94	0.87	16.26
Dolnoslaskie	328.76	109.57	1.33	23.19
kujawsko-pomorskie	309.71	N/A	0.86	16.52
Lubelskie	297.24	N/A	0.87	40.89
Lubuskie	308.14	101.82	0.87	19.59
Lodzkie	208.21	35.92	1.39	10.55
Małopolskie	286.64	N/A	0.85	19.23
Mazowieckie	320.81	N/A	0.70	19.13
Opolskie	318.07	N/A	1.07	4.37
Podkarpackie	341.37	N/A	0.89	15.38
Podlaskie	311.26	N/A	1.12	20.76
Pomorskie	314.44	N/A	0.82	7.59
Slaskie	275.68	N/A	1.04	23.09
Swietokrzyskie	316.90	N/A	1.45	22.48
warminsko-mazurskie	307.57	N/A	0.99	22.19
Wielkopolskie	324.67	68.87	1.24	15.95
Zachodniopomorskie	346.67	N/A	1.59	27.35

Source: URE, 2022, p. 81.

In the years 2016-2021, an increase in electricity sales prices in Poland was visible. The average annual sales price on the competitive market was 278.08 PLN/MWh in 2021. In the presented period, the cost of coal used for energy production also increased to 99.57 PLN/MWh in 2020. Table 12 displays households electricity prices including excise tax, and excluding VAT.

Table 12: Electricity selling price in 2016-2021

Specification	2016	2017	2018	2019	2020	2021
The average annual sales price on the competitive market [PLN/MWh]	169.7	163.7	19.3	245.44	252.69	278.08
The average annual sales price per household [PLN/KWh]	0.4987	0.5046	0.5055	0.4862	0.5374	0.5947
The average annual cost of coal used by plants (including transport of coal costs) [PLN/MWh]	82.27	83.43	83.74	98.20	99.57	N/A
The average price of electricity produced by coal power plants [PLN/MWh]	181.11	178.06	197.07	275.39	294.67	N/A

Source: http://www.ure.gov.pl [access: 06.08.2022].

The calculation of the energy price includes the costs of fuel purchase, capital cost recovery, renovation costs, maintenance costs, and excise duty costs. The TGE report shows that on

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the Day-Ahead Market the Monthly Weighted Average Price of electricity in July 2022 amounted to 1,125.94 PLN/MWh. For comparison, in June 2020 this price was 200 PLN/MWh (TGE, 2022, p.1). On the Balancing Market, the price of energy on July 4th, 2022, increased to the highest ever - 2,487.24 PLN/MWh The reason of such high price of energy was taken into account the price of EU hard coal market to produce energy in Polish power plants (https://wysokienapiecie.pl, [access: 06.08.2022]).

The **price of electricity** in Poland, paid by households, consists of the fee for the electricity consumed and the fee for the energy distribution service, which includes a fixed transmission fee, a network fee, a subscription fee, a transition fee, and a quality fee. The average electricity price until the end of July was 0.66 PLN/kWh including 5% VAT. However, from 01/08/2022 the VAT rate increased to 23% and the average price of electricity increased to 0.77 PLN/kWh. Additionally, the electricity bills include the power fee, the fee for RES and the cogeneration fee. When comparing electricity prices regionally, the electricity price ranges from 0.63 PLN/kWh to 0.70 PLN/kWh. The cheapest electricity is in Szczecin, Bydgoszcz, Poznan, Warsaw - 0.63 PLN/kWh, and the most expensive in Olsztyn, Gdansk and Torun - 0.70 PLN/kWh. In Lodz, the cost of 1 kWh for a household is 0.68 PLN/kWh (https://enerad.pl [access: 06.08.2022]).

1.1.5 Logistics and value chain of residual biomass

There are many transport companies in the Lodz region and finding a **biomass carrier** should not be a problem. However, not every transport company is able to transport wood waste. It depends on the transport fleet and other technical devices, as well as permits. On the websites of some companies involved in the transport of waste, the price for individual services can be found. However, most companies often set the price individually depending on the type, logistic conditions (e.g., on whether the raw material requires shredding or not), the exact type of wood waste, the duration of the obligation (one-off orders or long-term contracts). According to the price list on one of the pages, the cost of disposal or management of sawdust, shavings, cuttings, wood (waste code 030105) is 600 PLN net/tons (http://www.puk-zys.pl [access: 07.08.2022]). On another source, proposals for the collection of post-consumer wood waste can be found, especially large size with loading. The operator estimates the cost of collection of 20 m^3 of waste with loading at 2,200 PLN, and the rental of a 30 m^3 loading space costs from 2,500 PLN (without loading) to 3,500 PLN (with loading) (https://zlotnicki.pl [access: 07.08.2022]).

On the website ebiomasa.pl, prices of wood biomass, wood briquettes, wood pellets, chips, sawdust, wood, waste, charcoal, branches and many others can be found (http://www.ebiomasa.pl [access: 07.08.2022]). Here, examples of several products are available: board-wood chips, fractions up to 50 mm, price 370 PLN net/tons, the price of wood pellets ranges from 1700 PLN/tons to 2500 PLN/tons. The briquette prices range from

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1100 PLN/tons to 1900 PLN/ton. Sawmill sawdust from 100 PLN/m^3 to 140 PLN/m3. However, 170 PLN/m3 is the cost of sawmill saw chips (http://www.ebiomasa.pl [access: 08.08.2022]).

Transport companies are an important link in the circular value chain from the perspective of the management of wood biomass as well as wood waste. The transport of wood and wood waste is handled by many companies operating in the domestic and regional range. There are many possible solutions, and it seems that the market for collecting wood waste is relatively flexible. An interesting solution is the **WasteMaster** online waste exchange, through which you can order a waste collection service, including wood waste. The exchange brings together recycling companies that offer their services (https://mamodpad.wastemaster.pl [access: 08.08.2022]). Below are some examples of companies from the region as well as those operating on the domestic market.

Table 13: Examples of transport companies

Name of company	Scope of activities
EKO-SYSTEM Sp. Z o.o. Sp. k.	A company from Lodz, dealing with purchase and recycling of pallets (https://ekologistyka24.pl [access: 09.08.2022]).
Spółka TRAPEX	A company from lodzkie voivodeship, dealing with purchase, collection, recycling and selling of wastepaper, pallets and other post-production residues (http://www.tarpex.com.pl [access: 09.08.2022]).
ZŁOTNICKI GRUPA	A company whose headquarters is based in Lodz, dealing with collection of wood waste (https://zlotnicki.pl {access: 07.08.2022]).
Jantar	A company from lodzkie voivodeship, dealing with collection of industrial and large-size waste, recycling, car disassembly, document shredding and deleting data. Additionally, it produces alternative fuel (https://8888.pl [access: 09.08.2022]).
Skalec	A nationwide company, dealing with acquiring and using biomass for renewable energy purposes as well as for cellulose and paper industry and enterprises producing wood-based panels (http://skalec.pl [access: 09.08.2022]).
3Spare	A nationwide company, dealing with transport, shredding and sorting waste from municipal, energy and waste branch. (https://3spare.eu [access: 09.08.2022]).

Source: own study.

1.1.6 Overview of the Polish wood market

When analyzing woody biomass customers, including wood waste, apart from the energy sector, an important role is played by enterprises from the wood sector itself. These are important stakeholders from the perspective of the Polish and regional economy. Considering the data available on FAOSTAT regarding the **wood industry in Poland**, it can be noticed that the production of **wood fuel** in 2020 amounted to 4.7 million m^3 which showed a decrease by 368.9 thousand m^3 compared to 2019 (Table 14). The production of

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utility wood (i.e., wood to produce for example construction wood, furniture, paper; wood intended for industrial processing excluding firewood) was 35.9 million m^3. The export of this type of wood amounted to 3,567,504 m^3 which showed a decrease by 829,253 m^3 compared to 2019. The main export destinations were China, Germany, Sweden, and the Czech Republic. Imports of this raw material totaled at 2,134,426 and showed an increase by 527,382 m^3 compared to 2019. The Czech Republic delivered to Poland 60% of total imported utility wood. The other import origins are mainly Germany and Belarus. It should be noted that imports from Belarus accounted for 11% in 2020, while they covered 66% in 2015. The decrease in the amount of imported raw material was related to the reduction in the export of unprocessed wood from this country. That import direction was to be replaced by Ukraine, which was to abolish the ban on the export of unprocessed wood at the end of 2021. Additionally, 44% of exported utility wood goes to the Chinese market, but it should be emphasized that in 2017 this share was only 2% (https://www.fao.org [access: 06.08.2022], https://www.pkobp.pl [access: 07.08.2022]).

In Poland, the production of **round timber** amounted to 40.6 million m^3 in 2020. Imports amounted to 2.2 million m^3, and exports amounted to 3.7 million m^3. It is concluded that on the Polish market, round timber was available in the amount of 39.1 million m^3 in 2020. It should be emphasized that the supply of wood decreased in 2015 - 2020. In 2015, the supply was 41.3 million m^3 whereas, in 2017 it was 44.1 million m^3, and 39.1 million m^3 in 2020 https://www.fao.org [access: 06.08.2022]). Before the aggression on Ukraine, Russia produced about 30.6 million industrial sawn timber, of which 75% was exported. On 09/07/2022, due to the sanctions imposed on Russia by the EU, it is currently practically impossible to sell Russian sawn timber on the EU market (https://pigpd.pl [access: 03.08.2022]). Russia, Belarus, and Ukraine are important suppliers of wood to the EU market, mainly coniferous sawn timber, birch plywood and non-coniferous sawn timber – from oak trees. Imports of coniferous sawn timber amounted to 11.4 million m^3 in 2021. Birch plywood was imported from Russia in the amount of about 2.8 million m^3. Additionally, from Belarus, about 340 thousand m^3 of this raw material was delivered to the EU market. On the other hand, oak sawn timber was imported from Ukraine, for which there is currently no alternative. Ukraine, Belarus, and Russia account for 27% of the world trade in coniferous sawn timber (https://pigpd.pl [access: 07.08.2022]). It is estimated that the deficit on the wood market in Poland is at the level of 3 million m^3 in the form of large-size wood (https://pigpd.pl [access: 08.08.2022]).

Table 14: Production and balance of selected wood sector products in Poland in 2019-2020

Specification	2019				2020			
	Production	Export	Import	Balance	Production	Export	Import	Balance
Wood fuel, coniferous [m^3]	2,504,929	144,343	43,571	100,772	2,300,000	119,360	32,963	86,397

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Wood fuel, non-coniferous [m³]	2,563,973	60,529	18,712	41,817	2,420,000	28,433	14,349	14,084
Industrial round timber, coniferous [m³]	N/A	3,942,758	946,824	2,995,934	N/A	3,198,491	1,487,233	1,711,258
Industrial round timber, non-coniferous non-tropical [m³]	N/A	453,925	659,083	-205,158	N/A	368,821	646,514	-277,693
Sawlogs and veneer logs, coniferous [m³]	14,269,008	N/A	N/A	N/A	14,191,000	N/A	N/A	N/A
Sawlogs and veneer logs, non-coniferous [m³]	2,730,698	N/A	N/A	N/A	2,767,000	N/A	N/A	N/A
Pulpwood, round and split, coniferous [m³]	15,576,956	N/A	N/A	N/A	13,874,000	N/A	N/A	N/A
Pulpwood, round and split, non-coniferous [m³]	4,837,371	N/A	N/A	N/A	4,464,000	N/A	N/A	N/A
Wood charcoal [tons]	80,690	133,576	139,451	-5,875	95,000	169,400	136,214	33,186
Wood chips and particles [m³]	2,693,206	201,626	27,86,393	- 2,584,767	2,700,000	125,340	2,349,112	- 2,223,772
Wood residues [m³]	6,700,000	463,652	218,085	245,567	6,700,000	357,852	150,631	207,221
Recovered post-consumer wood [tons]	281,231	74,728	94,185	-19,457	275,000	50,288	49,600	688
Wood pellets [tons]	1,405,000	518,605	216,668	301,937	1,380,000	407,836	114,175	293,661
Plywood [m³]	518,746	286,245	369,031	-82,786	500,000	266,039	403,536	-137,497
Particle board [m³]	5,650,753	534,212	1,747,549	- 1,213,337	5,270,000	672,604	1,265,781	-593,177
OSB [m³]	938,055	364,100	124,257	239,843	930,000	379,696	149,021	230,675
Hardboard [m³]	102,345	42,373	14,520	27,853	100,000	34,173	13,502	20,671
MDF/HDF [m³]	3,655,906	1,067,879	721,170	346,709	3,550,000	979,788	693,059	286,729
Other fibreboard [m³]	1,109,390	856,301	13,356	842,945	1,050,000	923,815	13,373	910,442
Chemical wood pulp [tons]	937,781	113,977	1,007,794	-893,817	982,000	138,240	1,095,132	-956,892
Recovered fibre pulp [tons]	N/A	10,592	10,135	457	N/A	8,690	8,482	208
Newsprint [tons]	63,207	14,648	139,716	-125,068	11,000	15,829	129,240	-113,411
Printing and writing papers [tons]	750,528	552,532	1,042,940	-490,408	760,000	511,186	886,553	-375,367
Other paper and paperboard [tons]	4,065,998	1,858,232	3,139,932	- 1,281,700	4,130,000	1,958,052	3,228,788	- 1,270,736
Cartonboard [tons]	72,8011	338,591	684,750	-346,159	730,000	319,289	700,731	-381,442
Wrapping papers [tons]	140,343	210,788	340,883	-130,095	150,000	201,295	403,464	-202,169
Recovered paper [tons]	2,900,000	1,037,820	425,632	612,188	2,950,000	979,038	448,599	530,439

Source: own study, based on: FAOSTAT.

Poland produced a total of 10.35 million m³ of **wood-based panels** in 2020. The export of this product amounted to 2.33 million m³ and import to 2.52 million m³. It should be

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emphasized that the vast majority of wood-based panels comes from domestic production. Poland is the fourth producer of chipboards and OSB globally (6.2 million m^3), and sixth in the production of fibreboards and MDF / HDF (4.7 million m^3). Imports of wood-based panels such as OSB and chipboards come from Belarus (27.2%), Slovakia (18.4%) and Germany (14.1%). Fibreboards are imported from Germany (29.1%), Belarus (24.8%) and Russia (10.9%). On the other hand, plywood and veneered boards mainly come from Russia (30.4%), Belarus (26.6%) and China (16%). Sawn or planed lengthwise wood is mainly imported from Belarus (36.1%), Germany (14.3%) and Sweden (13.7%) (https://www.pkobp.pl [access: 03.08.2022]).

The largest producers of wood-based panels in Poland include Swiss Krono, Kronospan, Pfleiderer Group, Steico, Homanit Polska, Egger, Biuro Styl and many others. Additionally, IKEA should also be mentioned, which has 16 factories in Poland and is the second largest production centre after China. For the production of wood-based panels, Pfleiderer company uses 75% of raw materials from recycling and other industries. On the other hand, 80% of post-production waste generated during production process is reused for production of e.g., MFP (https://www.pfleiderer.pl [access: 08.08.2022]). **Pfleiderer Wieruszów Sp. z o.o.,** which is located in Wieruszów, in lodzkie voivodeship, has a production capacity of 690 thousand m^3 of wood-based panels (https://www.emis.com [access: 08.08.2022]). In the region, there is also **VMG Konstantynów Sp. z o.o.,** which is part of the international VMG Group. The company deals with wood processing and furniture production. The company has a production capacity of 1.6 million chairs per year and has a complete production and assembly process for chairs (https://vmg.eu/pl [access: 08.08.2022]). **Kronospam** company also uses raw materials from post-consumer and recycled wood for its production. The rest of the production residues are used to produce energy for their own use. There are nine factories of this company in Poland but none of them is located in lodzkie voivodeship (https://kronosfera.pl [access: 08.08.2022]). Another example is **FIBRIS** company that produces wood-based panels. It exports its products to 41 countries. It has four production lines with an annual capacity of 75 thousand tons of hardboards, 28 thousand tons of porous boards and 4.2 million m^2 of varnished boards. The company uses semi-finished wood from forest maintenance cuts and residues from other wood industry plants in 90% of its production. Additionally, they use biomass to produce the heat used in their plant (https://fibris.pl [access: 08.08.2022]). Another example of an international company operating in the wood industry in Poland is **STEICO**. All production is based on wood raw materials, with the company focusing on a closed production cycle. Laminated veneer glued in layers is produced from the trunk of the tree, while the wood-fiber thermal insulation boards or hard fiber boards are produced from the remnants of peeling. Part of the bark is used to produce energy. The company emphasizes that no excessive residues are formed in the production process. The company has 24 production lines in Poland (not located in

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lodzkie voivodeship). The company has a production capacity of wood fiber thermal insulation materials of 4 million m3 per year (https://www.steico.com [access: 08.08.2022]).

1.1.7 Technologies for the valorization of residual wood in Poland

While a variety of both thermochemical and biological technologies are under study in research and at pre-commercial technology readiness levels in the industry, it is important to focus on currently existing commercial technologies already in use in the Polish context, as well as on R&D projects ongoing in the region.

In Poland, it is common to **co-incinerate biomass** with, for example, hard coal. It is technologically possible by dust combustion, fluidized combustion, or grate combustion. Wood waste from the demolition of buildings or the production waste of wood-based panels (e.g., cuttings from MDF, chipboards, etc.) can be used for energy production. Wood waste, which comes from impregnated products, after shredding can be used as a fuel for energy production in enterprises authorized to use this type of energy carrier (based on waste)**. Direct incineration of waste is forbidden due to its contamination with chemicals, e.g., varnishes, adhesives**. The incineration of waste wood is allowed in special incineration plants equipped with exhaust and ash cleaning devices. There is a possibility of combustion, but after transformation into certified fuel, e.g., pellets or briquettes. Non-impregnated wood waste, after shredding, can be used for energy production or compost (Nolepa et al., 2018. p. 52-62).

The world emission of carbon dioxide amounted to about 36.3 giga tons in 2021 (https://www.iea.org [access: 10.08.2022]). Forests accumulate about 2.4 billion tons of carbon in the world. Trees accumulate the most carbon in the soil, as well as a significant part of it in the trunks. **Wood biomass gasification** is an attractive solution for energy production in combination with carbon sequestration. This modern technology enables the production of wood gas generally used in cogeneration systems for the simultaneous production of heat and electricity. The use of this technology enables the effective management of wood waste and the production of thermal and electrical energy. Char, the solid residues of the process, can be also valorized in different fields of application.

The problematic post-use wood waste are **railway sleepers**, which are impregnated with creosote oil, which is harmful to the natural environment. Railway sleepers are made of pine, oak, and beech wood. Experiments showed that railway sleepers can be thermolyzed. It is estimated that about 20 million sleepers can be recycled. The industrial recycling of railway sleepers requires adaptation of the logistics facilities and adjusting the construction of the WGW device for this type of waste. WGW Green Energy Poland Sp. z o.o. company improved the method of thermal decomposition of waste in terms of design and optimization (Wojciechowski et al., 2018, pp. 47-56). The company deals with the production of

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innovative technologies and devices for the utilization of post-consumer and industrial waste using the thermolysis method (https://www.pkt.pl [access: 09.08.2022]).

Geminus Sp. o. o. is a nationwide company, dealing with broadly understood waste management. It provides services in terms of waste analysis and selection of the optimal method of their use or disposal. They propose thermolysis technology for processing organic and mixed waste, including biomass and wood waste. Additionally, large-size waste can be put into the device without shredding it first. The technology is anaerobic, therefore no furans or dioxins are produced. The process produces oil-gas vapors that are subject to separation and condensation. As a result of these processes, an oil, gas or solid fraction is formed. The company has the know-how of WGW Green Energy Poland Sp. z o.o., including the patent P.408123 (https://www.pkt.pl [access: 09.08.2022]).

1.1.8 Comparison with an additional information collected in the South Tyrol region (IT)

To establish a comparison with residual wood supply chain in another context, UNIBZ was able to collect some information with the support of a major waste wood collection operator in the South Tyrol region, who hold clients in the whole Trentino-Alto Adige region, an area with a population of approximately 1 million. In this context, the Italian waste regulation imposes the delivery of any residual wood materials, or residual materials coming from upstream sorting of wood waste to authorized collectors. Based on the information collected, at the present market conditions, the operator receives 6,800 tons of material annually, which is divided as follows:

1. Residual wood from urban waste collection (25% of total)
2. Residual wood from wood packaging, including pallets at their end of life (25% of total)
3. Recovered wood from the construction and demolition sector (41% of the total)
4. Residual wood from wood transformation activities in sawmills and wood products manufacturing (0.03% of the total)
5. Mixed materials (plastics, glass, and wood) coming from the reject originating from upstream wood recovery operations (10% of the total)

Overall, the operator reported that at present their operations have already maximized the recycling of discarded wood into secondary markets to approximately 90% of the total incoming material, indicating a very virtuous practice, that is well in line with the figure reported above for the Polish context (87%). This suggests that, if the Polish average and the South Tyrolean case are not lone examples, the wood recycling sector already has the capabilities to achieve very high material efficiency levels in the European context.

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However, the market information collected by UNIBZ point to a relatively narrow space for energetic valorization of recovered wood, at least in the South Tyrolean context. More in specific, the source reported that recovered wood from the sectors mentioned above can be marketed back into secondary outlets at values between 40 €/t and 150 €/t, with higher quality (uncontaminated) materials coming from disposed pallets or other packaging and domestic waste in the higher value range, and lower quality (contaminated) materials coming mainly from the construction sector in the lower value range. For what concerns discarded pallets that can still be repaired, the secondary market is currently paying prices well above the 150 €/t mentioned abov, and often above 150 €/t, which makes the feedstock hardly affordable for an energy-oriented secondary market.

This seems to indicate that a competitive outlet for the valorization of residual materials in energy applications should withstand feedstock costs of at least 40 €/t for the poorer quality materials while delivering profitable outcomes if it were to purchase such feedstock from waste collectors. Alternatively, feedstock materials should be sought upstream in the value chain, though possibly at the cost of more complex and costly logistics.

1.2 Identification, involvement, needs and expectations from regional stakeholders involved in CSS1

1.2.1 Legal and formal expectations surrounding woody biomass and its by-products

Decarbonization is one of the main goals of the EU's climate and energy policy. Wood biomass is an important raw material for both the wood industry and the energy sector. Biomass used for energy purposes must meet the criteria of sustainability, energy efficiency and greenhouse gas reduction. The EU points out the necessity of calculating the balance of CO_2 emissions. Transforming land for biomass production can greatly exceed the benefits of using biomass fuels for energy production. The surplus of released carbon from transformed land can be much higher than the reduction in emissions of this gas when producing energy from RES. It is essential to carry out sustainable forest management to protect biodiversity, sequester CO_2, and meet the demands of the timber industry. The requirements for classifying forest biomass as a RES fuel are outlined by an EU directive called RED II of 2018 (EU Directive 2018/2001 of December 11, 2018, on the promotion of the use of energy from renewable sources).

Under EU law, any installation producing electricity, heat, cooling, and fuels with a total rated **thermal input of at least 20 MW** (i.e., any installation covered by the EU ETS) **for solid biomass fuels** or with a **total rated thermal input of at least 2 MW for gaseous biomass fuels is required to certify biomass** according to the NDS (sustainability criteria) in order to

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be considered for CO_2 reduction. Requirements for woody biomass for energy production are set forth in Article 29 of the RED II Directive. According to the RED II Directive, biomass without certification will not be considered as a decarbonized energy source, and therefore will not be eligible for subsidized conversion to energy. In addition, member states may apply the NER to installations with lower total rated thermal power (EU Directive, 2018). In Poland, biomass for energy purposes must meet sustainability criteria in line with the RED II directive, regardless of whether the biomass (e.g., charcoal) will be treated as a product or waste. The use of certified biomass fuel makes it possible to demonstrate a reduction in CO_2 emissions in line with EU ETS rules.

Certification systems that have received positive EU recognition include INiG's KZR, REDCert EU, ISCC EU, and SURE-EU (https://controlunion.pl [24.08.2022]). Biomass certificates can be issued by certification units that are recognized by the administrator of the UR system and are listed in the register of certification system administrators. In Poland, the Director General of the National Center for Agricultural Support (DG KOWR) (https://www.kowr.gov.pl [access: 24.08.2022]) is responsible for maintaining the register. On April 8, 2022, by EU Commission Executive Decision No. 2022/603, INiG's ZR system was approved to demonstrate compliance of biofuels, bioliquids and biomass fuels with the sustainability criteria (in accordance with Article 29 (2-5) and 10 of EU Directive 2018/2001). Pursuant to the mentioned EU decision, it demonstrates compliance with the NDS for such feedstocks as target crops of energy crops e.g. energy willow wood chips, agricultural waste/residues e.g. wood chips from fruit orchard residues, other waste/residues e.g. wood chips from cutting for investments, road lanes, urban greenery, removal of self-seeding trees from agricultural land, the wood industry remains e.g. sawdust, shavings, bark and wood pellets from sawmills and forest biomass processing plants. The authority (in Poland - DG KOWR) has not been given the authority to demonstrate compliance with the NDS described in Article 29 (6-7) of EU Directive 2018/2001, which deals with forest biomass in the context of its origin.

For installations up to 1 MW, standards for solid fuels are set out in the Regulation of the Minister of Energy on September 27, 2018, on quality requirements for solid fuels. The regulation covers coal fuels, not wood biomass such as wood pellets or charcoal for household boilers. **The Minister of Climate and Environment has adopted recommendations to set quality requirements for biomass fuels used in the household and municipal sectors** (https://www.teraz-srodowisko.pl [access: 24.08.2022]). The lack of quality standards for biomass fuels used in households creates a gap that allows certain abuses to occur regarding the composition of such fuel. Poor quality wood pellets contain hazardous substances, e.g., plastic, furniture waste, MDF, and plywood. Although wood pellets must comply with PN-EN ISO 17225-2:2014, which divides the fuel into three classes A1, A2 and B, elusions of the certification protocol are common. Such violations take place by submitting samples from good quality raw material in terms of sulfur, ash, and moisture

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content, to the testing facilities, while the product offered for sale is already of inferior quality. There is also a lack of control and monitoring. However, there would be the potential to undertake a virtuous use of the ash produced after burning good quality wood pellets, which can be used as fertilizer due to the content of such compounds as calcium, magnesium, phosphate, and soda (https://magazynbiomasa.pl [access: 23.08.2022]; http://igoz.org [access: 23.08.2022]; http://polskaradapelletu.org [access: 23.08.2022]).

In Poland, there are no clear regulations on the recognition of residues from wood industry production, e.g., wood-based panels, as a by-product or biomass. According to the position of the Chief Inspectorate for Environmental Protection (GIOŚ), it is forbidden to burn, for example, wood dust as its own raw material in wood-based panel production facilities. However, according to the EU BAT Conclusions, after the use of devices equipped with emission protection systems and compliance with environmental regulations, wood dust may be allowed to be burned in its own installations (https://www.drewno.pl [access: 23.08.2022]). In Poland, each waste producer is required to **keep waste records**, which are maintained in the database on products and packaging and waste management (BDO database) in accordance with the Waste Act of December 14, 2012, as amended and revised. Exemptions from the BDO database include municipal waste generators, individuals and organizational units that are not enterprises, which use waste for their own purposes. Pursuant to Article 27(8) of the Waste Law, an individual and organizational unit that is not an entrepreneur may recover only such types of waste, by such methods of recovery, as specified in the Regulation of the Minister of the Environment of November 10, 2014, on the list of types of waste that individuals or organizational units that are not entrepreneurs may recover for their own purposes, and using acceptable methods of recovery, and in such quantities that they can safely use for their own purposes (https://bdo.mos.gov.pl [access: 23.08.2022]; https://bdo.mos.gov.pl [access: 24.08.2022]). This also applies to entrepreneurs who will only generate waste with the codes and quantities listed in the Decree of the Minister of Climate of December 23, 2019, on types of waste and quantities of waste for which there is no obligation to keep waste records (https://bdo.mos.gov.pl/baza-wiedzy/ktore-podmioty-nie-podlegaja-wpisowi-do-rejestru-bdo/ [access: 24.08.2022]).

Table 15: List of examples of codes for wood waste by type of activity

Code	Name of waste
02 02 07	Waste from forest management
03	Waste from wood processing and the production of panels and furniture, pulp, paper and cardboard
03 01	Waste from wood processing and board and furniture production
03 01 01	Waste bark and cork
03 01 04	Sawdust, shavings, offcuts, wood, particleboard and veneer containing hazardous substances
03 01 05	Sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04
03 01 80	Wastes from chemical wood processing containing hazardous substances

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03 01 81	Wastes from chemical wood processing other than those listed in 03 01 80
03 01 82	Sludge from on-site sewage treatment plants
03 01 99	Wastes not otherwise specified
03 03	Wastes from the production and processing of pulp, paper and cardboard
03 03 01	Waste bark and wood
10	Waste from thermal processes
10 01 03	Fly ashes of peat and wood not chemically treated
10 01 14	Bottom ash, slag and boiler dust from co-incineration containing hazardous substances
10 01 15	Bottom ash, slag and boiler dust from co-incineration other than those mentioned in 10 01 14
19 01	Waste from waste incineration plants, including waste pyrolysis plants
19 01 10	Spent active carbon from waste gas treatment plants
19 01 17	Waste from waste pyrolysis containing hazardous substances
19 01 18	Wastes from waste pyrolysis other than those listed in 19 01 17

Source: own compilation based on https://odpady-help.pl [access: 24.08.2022].

In the mentioned regulation of the Minister of Climate, dated December 23, 2019, their type is specified. Considering woody biomass, the ordinance indicates forestry waste up to 10 tons/year (waste code 02 01 07), bark and cork waste up to 20 tons/year (waste code 03 01 01), sawdust, shavings, offcuts, wood, particle board and veneer and other than those mentioned in 03 01 04 up to 20 tons /year (waste code 03 01 05), wood packaging up to 1 tons /year (waste code 15 01 03), wood up to 10 tons /year (waste code 17 02 01) (https://dziennikustaw.gov.pl [access: 24.08.2022]).

Article 10 of the Law of December 14, 2012 on waste provides a **definition of a by-product, resulting from the production process, which is not waste.** According to the provision, the conditions must be met together:

- further use of the object or substance is certain,
- the object or substance can be used directly without further processing other than normal industrial practice
- the object or substance is produced as an integral part of the production process
- Article 10 of the Law of December 14, 2012 on waste provides a definition of a by-product, resulting from the production process, which is not waste. According to the provision, the conditions must be met together:
- further use of the object or substance is certain,
- the object or substance can be used directly without further processing other than normal industrial practice,
- the object or substance is produced as an integral part of the production process,
- the substance or object meets all relevant requirements, including legal requirements, in terms of product, environmental protection and human life and health, for the specific use of these substances or objects, and such use will not lead

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to overall negative impacts on the environment, human life or health (https://lexlege.pl [24.08.2022]).

The operator is obliged to submit a notification on the formation of a by-product to the competent marshal of the voivodship. The decision on whether or not to meet the conditions for recognition as a by-product is issued by the marshal after obtaining the opinion of the provincial inspector of environmental protection (https://codozasady.pl [24.08.2022]).

A draft of regulation by the Minister of Climate and Environment on detailed guidelines for the loss of waste status for **waste generated in the combustion process** (including fly ash from wood not chemically treated) is currently under development. After meeting quality standards, the materials or products will be able to be used, for example, as fertilizer. The work on the project is aimed at simplifying the procedures already in place, which were cumbersome for smaller companies (http://www.ichpw.pl [access: 24.08.2022]). **To date, according to Article 10 of the Law of December 14, 2012, on waste, waste generated in the combustion of fuels can be considered a by-product or, under Article 14 of the Law, can obtain product status by losing waste status.** The procedure itself, as a rule, mainly applies to larger energy companies that have cooperating companies that deal with by-products. Resolving the possibility of losing the status of waste generated in the process of fuel combustion will facilitate economic turnover. In contrast to the by-product status, it will not be necessary to have at least concluded contracts with customers, and a description of the production process by which the by-product will be managed (https://pracodawcy.pl [24.08.2022]).

Therefore, taking into account the above considerations, **the decision whether, for example, charcoal will be classified as waste or by-product or lose its status as waste depends on the specific example of the enterprise, the activity conducted, and the technology used.**

1.2.2 Stakeholder needs in the perspective of a more circular wood economy

The Lodz region has significant support for RES development in the area of access to knowledge. There is the Bioenergy Cluster for the Region. It is a cooperative initiative bringing together more than 80 entities operating in the area of RES, including 41 enterprises, 7 local government units, 11 scientific and research institutes, and 13 business environment institutions. The purpose of the cluster's activities is to provide support for the Lodz region in the development of bioenergy in the context of the implementation of the European Commission's actions to reduce emissions and fight climate change. Cluster's cooperation includes 45 projects implemented related to the subject of dissemination of knowledge and implementation of RES solutions. A **Technology Transfer Center** has been established in the Lodz Voivodeship, which is a research centre for renewable energy and circular economy. The mentioned Center includes a bioprocess laboratory, a biomass and waste validation

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laboratory, a solar energy laboratory, a wind energy laboratory, an energy efficiency and e-mobility laboratory, a natural products laboratory, a textronics laboratory, and an industry 4.0/5.0 laboratory. The biomass and waste validation laboratory, for example, conducts research on the energy parameters of wood pellets, wood briquettes, wood chips, fireplace wood, chipped wood waste and wood chips for industrial use, and waste such as RDF. In addition, the laboratory is equipped with an industrial biomass dryer and granulation line. It also offers the possibility of renting a production line for wood pellets (http://www.bioenergiadlaregionu.eu [access: 28.08.2022]).

In addition, there is a high academic potential in the Lodz region. The **University of Lodz** offers, among others, education in the fields of spatial economy, environmental management, biology, environmental protection, and biotechnology (https://www.uni.lodz.pl/ [access: 28.08.2022]). **Lodz University of Technology**, on the other hand, offers such technical faculties as power engineering, electrical engineering, and bioeconomy (https://p.lodz.pl [access: 28.08.2022]). The **Bionanopark** is located in Lodz, which has very rich research facilities, and a wide range of investment and incubation offers for high-tech companies and institutions (http://bionanopark.pl [access: 28.08.2022]).

Previous experience in the Lodz region indicates that **local communities** still have little interest in the wider use of raw materials for green energy production. The reasons are primarily cultural but are also related to institutional and organizational barriers, resulting from legislative tardiness and investors' lack of certainty about the profitability of investments in the long term due to constant changes in support instruments. Other problematic aspects include the lack of transmission networks in rural areas to distribute RES heat, the unwillingness of end users to take the heat, and the inefficiency of the supply side of substrates.

Research conducted in 2018 on the agricultural biomass market shows that problems in the development of the biomass market for energy purposes in the province of Lodz exist on the demand and supply sides. Conducted surveys among owners of farms in the Lodz Region, let to identify the following barriers on the supply side of these markets:

- Lack of goods surplus due to its use for the farm own needs;
- Significant fragmentation of farms;
- The dispersion of fallow areas and other land excluded from conventional agricultural production and their often small size in particular locations;
- The high cost of developing areas for energy crops;
- Lack of opportunities for the profitable sale of biomass;
- Lack of guarantees of systematic receipt of raw material;
- Lack of interest in biomass from the demand side of the market;

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- Lack of organized transportation of biomass to customers;
- Lack of knowledge and access to information on innovative opportunities for the energy use of biomass.

Among the main demand-side barriers were:

- uncertainty resulting from changes in the legal aspects of the RES Act, which created uncertainty among investors regarding the prediction of the market situation and the stability of operating conditions;
- changes in legislation relating to the recognition of energy produced as energy from a renewable source;
- the dominance of large capacity units in the energy market;
- the support provided, especially aimed at large biomass units, while there is a lack of support for distributed power generation;
- the lack of public acceptance of the location of biomass-to-energy enterprises, especially agricultural biogas plants, due to concerns about odor pollution (Szubska-Włodarczyk, 2018).

1.3 Requirements and success criteria to satisfy the implementation of the solutions required in CSS1

The requirements and success criteria to satisfy the implementation of the required solutions includes:

- the minimization of existing market failures,
- the scope and appropriateness of applying incentives,
- the identification of areas requiring intensification of the integration processes of regional stakeholders' activities,
- the availability and interoperability of databases related to CSS1 activities.

Each market development faces various constraints in the form of market failures. The most common categories of market failures are public goods, externalities, imperfect competition, incompleteness of the market, and asymmetrical information (Randall, 1983, Stiglitz, 2004, Moreau, 2004, Jackson, Jabbie, 2019). Others also add incomplete property rights to this list (i.e., Perman et al., 2003; Acheson, 2006). A different approach was presented in the evolutionary economy, where the market is perceived as dynamic, chaotic, and constantly changing, rather than tending to a state of equilibrium (Nelson, Winter, 2002, Nelson, 2008,

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Schmidt, 2018). From this point of view, market failures typical for a neoclassic economy are not failures.

In this report, we looked at the **market failure** from the circular economy (CE) perspective. In a circular economy, it happens more often to identify the barriers which derail or slow down the transition (Kirchherr et al., 2018). The most common categories of barriers are: technological, economic, institutional and social. De Jesus and Mendonça (2018, p. 77) introduced an additional classification for the above barriers. They divided them into hard ones and soft ones. Hard barriers are related to techno-economic, and soft ones, are relazted to regulatory and social issues.

The economy of Lodz Region is still in process of transition to CE. That is why, we decided to identify "classical" market failures, which are universal for all areas and entities operating within the circular economy. Our research aimed to identify market failure in the circular economy and to assess the level of their occurrence in the Lodz Region. The research was conducted among four groups**: business, government, academia and society**, who we consider as main actors in the market. To achieve the aim, we conducted a two-stage engagement process:

1. **Quantitative stage**: Survey – online survey conducted among representatives of four mentioned groups. A separate survey was prepared for each group.
2. **Qualitative stage**: Focus Group Interview (FGI), conducted among representatives of mentioned groups, with the same respondents. FGI research allowed verification of survey results and their interpretation.

In the case of CSS1-Wood packaging, we can identify five main market failure categories: **public goods, externalities, imperfect competition, incompleteness of the market, and asymmetrical information**.

For the proper development of the circular economy and the creation of a cluster, three main issues have been identified:

- Good and stable legal regulations (market failure - public goods),
- Awareness of the need of using secondary raw materials and the benefits of this, and willingness to cooperate with potential cluster participants (externalities);
- Effective and efficient collection and delivery of materials to recipients (incompleteness of the market).

Unfortunately, in all these elements, in the case of the Lodz Region, we can talk about significant deficiencies or a high level of occurrence of these market failures. To distinguish the most significant market failures for individual groups of actors engaging in the circular economy and the circular cluster, which is the embodiment of industrial symbiosis, the matter is as follows:

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- **For entrepreneurs**, the leading market failures are, on the one hand, uncertainty and freedom of interpretation of Polish and EU regulations by public authorities, which sometimes prevents operators from reusing raw materials containing any additives (public goods and imperfect competition), and on the other hand, constrains even a pre-processing of wood products (except wood waste, packaging and pallets) limiting the possibility of their reuse, even for energy production (incompleteness of the market);
- **At the government level**, a serious barrier is the legal regulations in force (public goods) and an underdeveloped (or not developed at all) public procurement system promoting products and services using externalities;
- The main barriers **for the community** are the low level of awareness of the circular economy and its challenges (imperfect competition and information asymmetry) and minimal opportunities for regular and convenient disposal of wood raw materials - occasional large-size collection, remaining wood items go to mixed waste or, possibly, they must be delivered to a selective municipal waste collection point (in pl - PSZOK) on their own, which increases costs and in practice minimizes the chance of increasing the use of this type of raw material by processors and/or users (incompleteness of the market);
- On the other hand, considering **the academic community**, it is possible to point to the lack of complete information about the current market needs of academics (information asymmetry), but also too little importance devoted to designing solutions and products made of wood right away with a view to the possibility of reusing them (incompleteness of the market). It may be due to the low level of R&D staff transfer and other entities engaged in activities in the area of circular economy (externalities).

Cambridge dictionary defines an **incentive** as something that encourages a person to do something (https://dictionary.cambridge.org [access: 24.08.2022]). Given that CE has such a wide variety of stakeholder groups involved, we assumed that circular economy incentives encourage all relevant stakeholders to implement circular economy into action.

In the conducted research, the qualitative method was used with three different research techniques. The first was the technique of overt participant observation, the role of the total observer was assumed (Babbie, 2004, p. 309; Marshall, Rossman, 1995, p. 60). The first observation was carried out on April 6, 2022, at the enterprise site of the "Eagle Pond" Municipal Waste Disposal Plant located in Prazuchy Nowe. All the important facilities associated with the site were visited. Additionally, we gained knowledge of the technologies and the overall idea of the plant operation. During this time, photographic material was collected, documents and supporting materials were gathered, and discussions were held

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with key, and for the moment, potential respondents, who were then invited for in-depth interviews.

Secondly, individual interviews with a standardized list of information (IDI (Individual In-Depth Interview) were conducted. The research tool was scientific and research dispositions, i.e. a list of information sought. Four interviews were conducted with key people on the issue of the circular economy. These were officials from the Department of Environmental Protection of the Marshal's Office of the Lodz Voivodeship, the Provincial Environmental Protection Inspectorate, the Orli Staw Municipal Waste Disposal Plant (ZUOK) and a representative of Ekotechnologie company. It should be noted that the respondents were treated as experts on the subject under study, and were selected in a targeted method.

The study also used qualitative data analysis, which consisted of the value of observations made through the use of participatory observation, content analysis of the materials collected and qualitative interviews conducted, as well as analysis of the literature on the subject (scientific articles, reports, EU studies), which indicated the current system of incentives within the implementation of the circular economy in the Lodz region and beyond. The purpose of the study was to show the regularity of the phenomenon through the typical characteristics of qualitative data analysis: frequency, intensity, structure, processes, causes, and consequences of the process (Lofland, 1995, pp. 127-145).

The incentive system to support the implementation of CE can be considered for specific groups of waste: Plastics and Rubber , Water and Nutrients, Food and Feed, **Wood Packaging.**

Incentives can be dedicated directly to entrepreneurs and other entities operating in industries specific to a considered waste group, as well as universal, and independent of waste type. As part of the survey, respondents diagnosed both types of incentives, claiming, however, that very few are dedicated and most are universal incentives for waste (raw materials) in general. An example of universal incentive is the system of grants and loans from the National Environmental Protection and Water Management Fund (NFOŚiGW) and WFOŚiGW for the implementation of tasks in the field of environmental protection, including those aimed at implementing CE, provided that the specific task is included in the priorities set for the given year in a resolution of the Board of Directors of the respective Fund. Individuals, entrepreneurs, social organizations, local government units and state budgetary units can apply for these funds.

Wood waste is not a problem, it gets a second life offhand. It use as a raw material is therefore very common. The waste that results from logging is immediately sold to the local society.

Old boards and wood recovered from wooden pallets or furniture are used to produce horse bedding, gardening primer, wood pallet brackets and even new floorboards and furniture. Post-consumer wood products are not qualitatively or visually different from virgin wood

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products. In addition, they are often even preferred due to the fact that, unlike fresh wood from the forest, they are already dried.

The main incentive for the reuse of wood by entrepreneurs is the economic rationality of the enterprise and the possibility of increasing profit, for the reason that the supply of wood from the forests is disproportionate to the needs of the market. In addition, its prices are constantly increasing. The availability of by-products from sawmills, which are used in the production of panels, is also limited. The industry has to compete for sawdust and shavings with the power industry, which buys huge amounts of them to generate biomass energy subsidized as RES. The recovery and reprocessing of wood is therefore not only justified from an ecological point of view but is economically necessary.

The process of incentivizing (to implement the objectives of CE), i.e. sending and receiving incentives can be presented by means of the model of communication functioning (Griffin, 2000 p. 554; Dobek, 2002, p. 13; Drzazga, 2004, p.13). The stakeholders of change and therefore the subjects of the process of incentivizing will be Sender (Source) and Recipient (Audience). The message will be equivalent to a specific incentive. The research conducted reveals six types of incentive (communication) process models:

1. One-way and two-way communication model: one Sender, one Incentive, one Recipient
2. Mass communication model: one Sender, one Incentive, several Recipients
3. Sector Communication Model: One Sender, One Incentive, Recipient Sectors
4. Multiple Sender Communication Model: multiple Senders, one Incentive, One Recipient
5. The communication model of the plurality of Senders and Incentives: multiple Senders, multiple Incentives, one Recipient
6. The Communication model of the plurality of Incentives: One Sender, multiple Incentives, one Recipient

The sender formulating the incentives will be first of all the Government, but also in a few cases, the other CE market actors: Society, Company and Academy. The recipient of the incentive, on the other hand, will be mainly the company and Society, and marginally Government and Academy.

Referring to the identification of areas requiring the intensification of the **integration processes of regional stakeholders' activities**, attention should be paid to the specific type of network organization to be created. An essential element for the existence and development of a circular economy at a regional level can be the presence of clusters operating according to circular economy principles. Clusters have a chance to develop in a territory that has specific characteristics. Contrary to expectations, the territory, i.e. formal

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and informal institutions, social capital, explicit and tacit knowledge, and specific resources, determines whether a particular environment has produced a proper ecosystem. This ecosystem must be ready to build network relationships based on trust, cooperation and competition simultaneously. In the case of circular clusters, on the other hand, this environment must have solid environmental awareness. It is a crucial factor because ecological maturity allows or does not allow different stakeholders to build cross-sector business relationships (allows circular chain value creation). Therefore, one of the important studies carried out in the Lodzkie Region CRC area was to identify the degree of integration of activities of stakeholders potentially interested in building CRCs.

The implementation of the circular economy requires the involvement of all four groups of partners responsible for creating CRC: company, academy, society and government. This involvement requires monitoring and coordination. Such coordination should be the domain of public authorities at both the local and regional levels. Integration of activities induces synergy processes and is therefore a function of the speed of change and the dynamics of regional development processes. This element is particularly important when talking about systemic changes - the evolution of a free market economy operating under a linear production model into a circular economy. However, it should be highlighted that integration of activities on a regional scale (CRC) does not necessarily mean direct cooperation between partners. It is most important that the activities of individual partners affect the resolution of the challenges of the other partners to the greatest extent possible. Hence the importance of the study, which aims to identify the scope of impact of the projects implemented by individual CRC stakeholders on the realization of the challenges and objectives of the projects of the other regional partners.

The Leopold Matrix method was used to achieve this goal. The method makes it possible to assess the level of relations between regional partners as measured by the degree of the synergy of their projects. In Frontsh1p, this method was modified to identify the levels of integration between 4 sets of partners: company, academy, society and government. The study analyzed: 187 projects.

The research allowed to identify four types of impacts: intra-sectoral interaction (specific impact), cross-sectoral interaction (between two sets of partners), cross-sectoral interaction (between three sets of partners) Integration (simultaneous integration between all collections of partners) (Figure 4).

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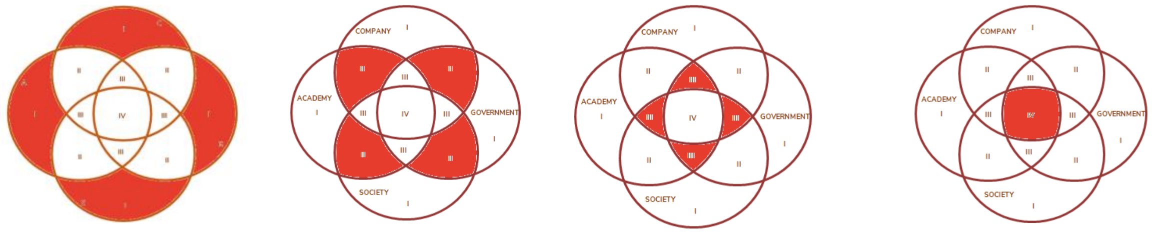
Figure 4: Types of interactions between projects and indicators



[I] intra-sectoral interaction (specific impact)	[II] cross-sectoral interaction (2.level)	[III] cross-sectoral interaction (3.level)	[IV] Integration

Source: own compilation.

Analysis of the synergy of aims and results of CRC stakeholder activities in the Lodz Region at the beginning allows concluding that projects have been identified in each group that strengthens CE building. However, the sum of such projects is small: 187 projects, implemented in the period 2014-2021 (Company and Academy) and 2019-2021 (Society, Governance). Thus, one can speak of a low level of project involvement of CRC stakeholders in Lodz Region in strengthening CE.

The number of projects that strengthen CE building varies due to the availability of information in the databases and the size of the projects. Nevertheless, it can be noted that in the Company (28) and Academy (28) groups, the selected projects directly relate to activities involving green technologies and are related to environmental protection in various aspects. On the other hand, in the Society (99) and Governance (32) groups, the majority of projects involve activities indirectly related to strengthening CE. Most often, these are projects that strengthen the sense of responsibility, level of participation and social activation, sharing of things, services or reduction of consumption. Less often, these projects involve processes related to recycling and reusing things. The three times higher number of projects in the Society group is due to their fragmentation and small scale of activities. Nevertheless, projects of this type are characteristic of activities undertaken by residents and local community groups. To sum up, projects undertaken directly by local authorities (Governance) and the local community (Society) are rarely about empowerment or inclusion in the Circular Value Chain.

Analysing the findings on the interactions between the regional partners' project activities, it is important to note the relatively large variation in the average ratings for each impact category (Figure 5).

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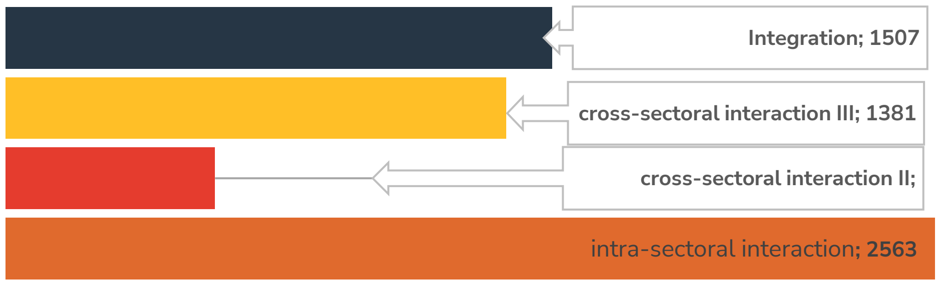
Figure 5: Average ratings of synergistic interactions between stakeholder groups



Source: own compilation.

The vast majority of implemented projects by CRT stakeholders are sectoral (2563). These projects do not affect the achievement of results by other partners. They are important from the point of view of strengthening the sector's internal competitiveness, but their synergistic effects on the local and regional environment are marginal. Optimally, the quantities identifying the different levels of impact should be high and balanced. The lack of this level of sustainability is especially underscored by the fact that the assessment of interaction impacts is five times lower (577.25), concerning partnership relations between two groups of stakeholders.

It is difficult to speak of a sustainable level, nevertheless, it is worth noting that there were cross-sectoral projects in the region that effectively achieved their goals and contributed to the achievement of results in three groups (1,381) or all stakeholder groups (1,507).

The most important image illustrating the scope and needs for coordination of integration activities is given by the analysis at the detailed level (Figure 6). This diagnosis indicates the weaknesses and strengths of particular partnerships between regional stakeholders. It is also important to remember that it is not the existence of formal partnerships. Often, in this case, the strength of synergistic effects depends on the level of awareness and tacit knowledge in the CRC.

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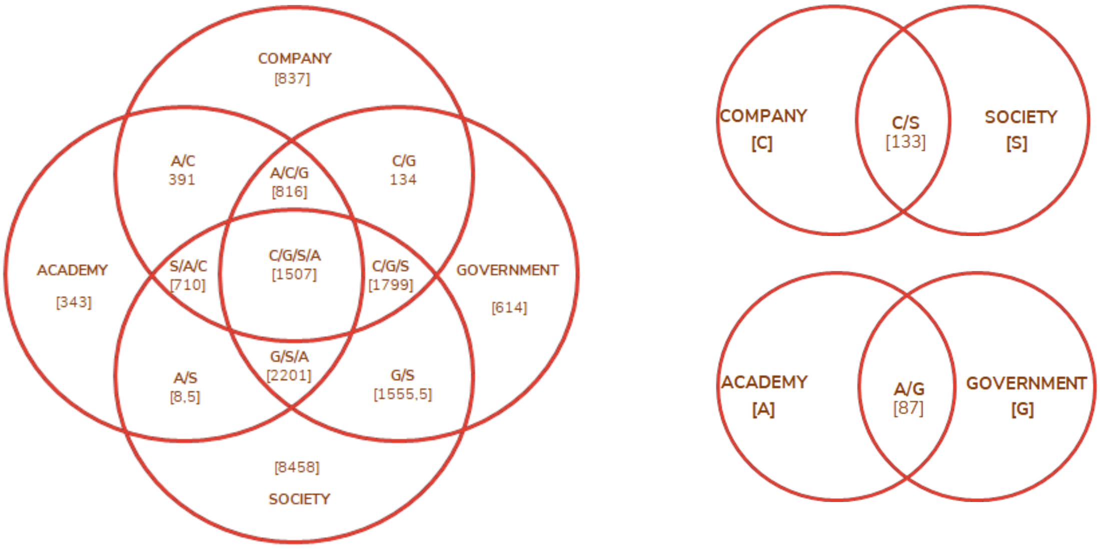
Figure 6: Scope and levels of synergistic effects among CRC stakeholders in Lodz Region



Source: own compilation.

In intra-sectoral interaction, the highest level of self-management of development processes within the sector is observed in the Society group (8458). On the one hand, this is good information. On the other hand, the height of this indicator can be interpreted as a closure of the sector to interactions with other sectors. This conclusion is supported, in particular, by the values of second-level interactions between Society and Company (133) and Society and Academy (8.5), which are practically non-existent. The convergence of the Society sector's internal goals is mainly due to the effect of copying the ideas of neighbours and the specificity and monoculture of non-governmental institutions at the local level. In the Government and Company sectors, the ratios are significantly lower, respectively: 614, 837. Nevertheless, it can be considered that these values are at the average level. In this case, the interaction between the objectives of the projects was determined primarily by the availability of project funding sources. It is about the orientation of the subject matter of the projects by the terms of the grants. The lowest value of the intra-sectoral interaction index is identified in the Academy sector (343). This is related, on the one hand, to the low budget 0for R&D in Poland, sectoral closure and individualism determined by the low degree of territorialization of academic sector entities in the Lodz Region. Sectoral closure usually means the implementation of partnership projects but based on industry similarity of partners, rarely spatial proximity.

The situation at the second level interaction is also a challenge. There is a lack of cross-sectoral sustainability. On the one hand, four areas of neglect can be identified: Academy/Society (8.5), Academy/Government (87), Company/Society (133) and Company/Government (134). The processes of synergistic effects between these areas hardly occur. On the other hand, one can see a positive picture of project relations between

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the Academy/Company sectors (391). This is not an indicator of a particularly high value, but nevertheless, this scope of cooperation is particularly desirable and difficult in Polish conditions, so it is worth highlighting. On the other hand, the value of the indicator of relations between sectors is high: Government/Society (1555.5). This means that local authorities influence the behaviour of residents to a large extent and can carry out coordination activities with great effectiveness.

Particular attention should be paid to the Third level of interaction and integrated impacts. It can be seen that in projects implemented in a group of Government or realizing its goals, the interaction has a balanced and relatively high level (from 1507 to 2201). In another case, for example, in the sets: Society/Academy/Company (710) the value is less than half. We can conclude that the goals of projects that coincide with local or regional development policies have a significantly higher potential for synergistic effects. This also means that an extremely important role has to be played by local and regional Government in the transformation of the traditional economy to a circular economy in the Lodz Region.

In Lodz Region in particular in the CRC, care should be taken to strengthen the synergies obtained through public, private and social investments. Projects undertaken by all regional partners, above all, should be implemented far more often in scopes related to the formation of CE. This effect can be achieved not only by increasing investment budgets but, above all, by targeting resources more precisely to the goals of CE implementation. In this regard, it is also worth emphasizing the importance of Green Public Procurement, which is used to a minimal extent. In contrast, the potential of targeted public spending is high.

Data interoperability cannot be equated with data integration, which aims to synthesize data from different, independent sources into a unified schema. Data interoperability requires the implementation of both data integration and exchange, so the stakeholders must have access to databases. Interoperability is not a purely technical matter. It is connected with: the organizational level, semantic level and technical level (Pagano et al., 2013, pp. 19-25; Masud, 2016, pp. 127-135). The technical level is the most important because it allows for developing the remaining interoperability components.

The methodology of research concerning databases is based on the desk research method. The aim of the study was: the identification of databases containing information related to the circular economy in the region, in particular in the area of Circular Systemic Solutions of the project; identification of gaps in database characteristics; and identification of the level of database interoperability at the technical level.

The desk research allowed us to identify ten databases with information connected to the Fronsh1p project. These databases owners were: Statistics Poland (three databases), the marshal's office in Lodz (2 databases), the Ministry of Climate and Environment (two databases), the Head Office of Geodesy and Cartography (one database), the Ministry for

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Education and Science (one database) and the Patent Office of the Republic of Poland (one database).

In the case of CSS1, spatial and statistics databases will identify supply chain components allowed for refurbishing, reusing, recycling and the next step of developing CTC energy recovery. The databases allow building basic sustainability in the case of wood packaging. It will be possible after adding some data connected with it. The problem is that the information about the wood packaging must be collected by the entities wanting this type of data. Another way for information about the wood packaging in the regional ecosystem is to build the geosystem, which allows for real-time interaction between the chain elements and creates different types of databases, both spatial and statistical.

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2. Plan for citizens engagement in activities carried out under the Circular Systemic Solution (CSS) 1 "Wood packaging "

2.1 Introduction

The report final section will present a road map of diagnostic research and implementation activities to engage citizens in the activities implemented under CSS1.

2.1.1 Characteristics of social involvement in circular economy and its indicators in EU literature and documents

The study is based on the literature.

Title: "Indicators of social commitment to the circular economy".

Implementation methods: descriptive analysis of desk research literature.

Schedule: December 2021 – March 2022.

2.1.2 Definition of citizens engagement in a circular economy (CE)

The study made on the basis of literature, will be interactively modified in the course of implementation of the activities provided for in this plan.

Methods of implementation: descriptive analysis of *desk research* type literature and expert discussion.

Schedule: implemented in March – April 2022 (version 1);

June – September 2022 (version 2).

In the future, the wording of the definition might be updated (according to the identified problems, in particular with regard to the forms of citizen involvement and the possibility of supporting them).

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Content of the definition (abbreviated):

Citizens engagement in the circular economy refers to the involvement of the public (households and communities) in activities (processes) for the implementation of the solutions that make up the circular economy system (CES), otherwise known as the circular economy (CE) or closed-loop economy (CLE). This concept means, first of all, involvement in real processes related to management (processes from the real sphere), that is, undertaking specific **practices**, i.e. those that bring material effects consisting in increasing the degree of circulation of natural resources in the socio-economic system, and, consequently, in reducing the anthropogenic impact on the natural environment, first of all, from generation and accumulation in it of various types of waste, mainly the post-consumption waste, i.e. the waste accompanying consumption (therefore, this refers mainly to the so-called municipal waste).

The practices of households in the field of CE may be initiated and supported by various types of activities (instruments) undertaken (applied) by public entities, non-governmental organizations, etc. These **supporting activities** should also be analyzed as part of research on social involvement in CE.

Social involvement in a closed loop economy, in a broader sense, may also refer to regulatory processes related to management (processes from the regulatory sphere), i.e. those that are related to designing of organisational solutions aimed at increasing the degree of natural resources circulation in the socio-economic system, and thus reducing the anthropogenic impact on the natural environment, mainly from generation and accumulation of various types of waste, mainly post-consumption waste, i.e. waste that accompanies consumption (thus mainly municipal waste).

We define the activities of citizens (households) for the circular economy as real (and not only declarative) involvement in the following practices and processes:

- **refusing** (e.g. not necessary consumption of goods; elimination of unnecessary / harmful consumption),
- **reducing** (consumption of goods in order to lower the physical flow of matter in economic processes),
- **reusing** (the multiplication of the use of material goods for their current purpose),
- **refurbishing** (renewal of material goods in order to restore the original functionality and extend the life time),
- **repairing** (fixing of broken or damage material goods),
- **repurposing** (finding new applications and functionalities for material objects already used up for their original purpose),

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– **recycling** (processing material goods into new, **secondary raw material**),

as well as activities not directly related to CE, but supporting such practices:

– **sharing** (using one item / material good together with other households in order to increase the intensity and efficiency of use),

– **leasing** (rental systems of material goods).

and **segregation** and **selective collection** in the local waste management system.

Analyzing (researching) **activities supporting** the involvement of citizens (households) in the above-mentioned practices for the benefit of circular economy will consist in assessing the effects of **initiatives** undertaken by public institutions, non-governmental organizations or other entities, such as:

a. **activities increasing awareness and knowledge** of issues related to the circular economy (soft activities),
b. **actions modifying the behavior of citizens** (households) in the sphere of managing material resources, in an **institutionalized manner**, i.e. as a result of the application of legal and administrative coercion, as well as through a system of incentives and / or negative incentives – respectively: forcing, stimulating or discouraging to specific activities (practices) (hard actions of a command-control nature, regulations and economic instruments);
c. **activities involving citizens** in the process of **creating system and regulatory solutions** in the field of circular economy (activities such as: regulations by reaching an agreement and co-creating policies and participation in decision-making processes);
d. **activities encouraging citizens** (households) to behave and practice consistent with the concept of circular economy, introduced by private entities on the basis of **self-regulation** (voluntary regulation).

Ad. (a) awareness-raising and awareness-raising activities are targeted at citizens as audiences and include, inter alia:

a. information activities,
b. educational activities,
c. promotional activities (e.g. targeting the creation of new social trends in the field of CE),
d. advisory activities.

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Awareness and knowledge-raising activities can be carried out by very different entities, i.e.:

a. national (central), regional and local authorities,
b. non-governmental / social organizations, social partners (?),
c. private and public enterprises,
d. educational and educational institutions..

Ad. b) actions modifying the behavior of citizens (households) in the field of managing material resources, in an institutionalized way, they include legal regulations and economic / financial solutions that can be introduced by local, regional and central authorities to persuade, force, encourage or punish a citizen for application or non-compliance with specific practices in the field of circular economy, and which are of interest to public policy (public interest sphere). These activities include, for example:

a. introducing an obligation to segregate and separate waste collection,
b. introducing a system of fees (e.g. for products, recycling) and penalties, as well as subsidies by national / local government authorities,
c. introducing an obligatory deposit system when using specific packaging by producers,
d. other.

Ad. c) activities involving the process of creating systemic solutions, including in particular regulatory ones, in accordance with the principle of co-management (governance by co-governance) – they include the involvement of citizens as participants and stakeholders in the processes related to the organization of the material resource management system itself (in particular waste management) on levels: strategic, operational and related to the creation of draft legislative solutions to support circular economy. These activities can be implemented on various scales: local / regional / national and may include, for example:

a. participation of citizens in consultation processes and co-creation of various types of public documents (concepts, policies, strategies, plans, programs) describing the directions of activities relating directly or indirectly to the issues of circular economy,
b. participation of citizens in legislative initiatives (e.g. legislative initiative),
c. participation of citizens in advocacy and lobbying activities (including, for example, petitions to the authorities),
d. activities undertaken by citizens within the so-called non-statutory planning,
e. other.

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Ad. d) activities encouraging citizens (households) to behave and practice consistent with the concept of circular economy, introduced by private entities (e.g. commercial establishments, service entities) on the basis of self-regulation (voluntary regulation). This includes activities such as:

a. voluntary introduction of deposit systems, e.g. for the return of certain types of packaging,
b. introducing free collection services for used tangible goods when purchasing a new one,
c. others.

2.1.3 Comments on the social acceptance of the circular economy

The study is based on the literature.

Implementation methods: descriptive analysis of desk research literature and expert discussion.

Schedule: March 2022.

2.2 Scope and areas of citizens (households) engagement under CSS 1 "wood packaging"

2.2.1 Identification of the expected citizen (household) involvement for a given CSS

As part of this section, the feasibility of applying circular economy activities at the household level will be assessed, which, as a result of the previous analysis, included the following **practice**s:

– refusing,
– reducing,
– reusing,
– refurbishing (renewal),
– repairing (fixing),
– repurposing,
– recycling (processing),

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- sharing,
- leasing (rental),
- segregation
- selective collection in the local waste management system.

The analysis will take into account CSS "wood packaging" specific practices, including in particular refusing, reducing, repurposing and others beyond the analyzed scheme, e.g. The starting point for performing such an assessment is a technical report. The assessment is to demonstrate to what extent an action (practice) from the group is necessary for the introduction of the designed technical solutions for CSS1-Wood packaging in the local/regional circular economy system.

Table 16: Analysis/assessment chart of the feasibility of household practices for implementing solutions in each CSS

Practice name (practice categories)	CSS Wood packaging
Refusing	
Reducing	
Reusing	
refurbishing (renewal)	
repairing (fixing)	
Repurposing	
recycling (processing)	
segregation and selective collection in the local waste management system	
Sharing	
leasing (rental)	
other practices specific to CSS	

NOTE: the table is used to initially identify the link between a given practice type and the activities anticipated under a given CSS type, using the following designations:

- practices needed to implement CSS (PN),
- practices to support CSS implementation (PS),
- general practices - i.e., directly unrelated to the implementation of CSS (to increase citizens engagement in circular economy solutions in general (GP),
- lack of practices adequate for the activities envisioned in a given CSS (LP).

Source: own study.

Methods of implementation: surveys with the participation of leaders of individual CSS and WP activities and also descriptive analysis of the survey as well as expert discussion.
Schedule: November 2022 – January 2023.

2.2.2 Characteristics of the expected household practices identified for CSS1

For each category of practice identified for a given CSS, a subject (essential) description will then be made of the activities that households are expected to undertake. This description

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will provide a characterization of the expected households engagement in activities in a given CSS.

In the summary of the description, a breakdown of the activities can be made:

- indispensable – i.e., conditioning the ability to implement the technological activities envisaged in the project;
- supportive – i.e., enhancing the effectiveness of the implementation of technological activities envisaged in the project, but not necessary for its implementation;
- general – i.e., raising the general level of public awareness of the need to take action for the circular economy on the issues addressed in a given CSS.

Conducting the analysis indicated in Table 16 and then performing the above description will further allow us to determine whether there are any areas of common practice for each CSS, which can then be standardized at the regional/local implementation level (Table 17).

Table 17: Assessment of the feasibility of direct household practices for implementing solutions in each CSS – summary table

Practice name (practice categories)	CSS type / name			
	CSS 1	CSS 2	CSS 3	CSS 4
Refusing				
Reducing				
Reusing				
refurbishing (renewal)				
repairing (fixing)				
Repurposing				
recycling (processing)				
segregation and selective collection in the local waste management system				
Sharing				
leasing (rental)				
other practices specific to CSS				

NOTE: the table is used to initially identify the link between the type of practice and the activities envisaged under the type of CSS, using the following designations:

- practices needed to implement CSS (PN),
- practices to support CSS implementation (PS),
- general practices – i.e., directly unrelated to the implementation of CSS (to increase citizens engagement in circular economy solutions in general (GP),
- lack of practices adequate for the activities envisioned in a given CSS (LP).

Source: own study.

Methods of implementation: Descriptive analysis of the survey, comparative analysis and expert discussion.

Schedule: February – April 2023.

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2.3 Types of activities dedicated to supporting social involvement/ engagement in CSS 1 (analysis of conditions and selection of instruments)

2.3.1 Identification_of the determinants of social involvement of citizens (households) and the possibility of undertaking practices for activities in a given CSS

The activity will identify the determinants that influence households to undertake the practices identified in 5.2.1 and 5.2.2 for CSS. The logic diagram for such identification is presented in Table 18. This analysis will be carried out separately for each CSS.

Table 18: Diagram for identifying / analyzing / assessing the determinants of the application of household practices for the implementation of solutions in the framework of CSS 1 "Wood Packaging"

Determinants of social commitment / citizens (households) engagement in CE (CSS)	**Name of practice (practice categories)**										
	Refusing	**reducing**	**reusing**	**refurbishing (renewal)**	**repairing (fixing)**	**repurposing**	**recycling (processing)**	**segregation and selective collection in the local waste management**	**sharing**	**leasing (rental)**	**other practices specific to CSS**
Technology (increasing accessibility)											
Awareness and knowledge (improvement through education)											
Coercion (creation of legal and administrative solutions with an enforcement mechanism)											
Stimulus: stimulant / destimulant (creation of economic and financial solutions)											
Best practice (dissemination, popularization)											
Cultural pattern (creation and dissemination)											

NOTE: the table is used to identify the determinants of social engagement of households in undertaking practices for the implementation of activities/solutions envisioned in a given CSS. Identification using scale:

- very important / key condition (conditioning the effectiveness of CSS activities - essential),
- essential condition (supporting the effectiveness of CSS activities),
- conditionality generally supportive of public commitment to CE,
- no relationship or marginal importance of a given determinant for undertaking practices in a particular area (no or insignificant impact on the implementation of activities under a given CSS).

Source: own study.

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Methods of implementation: Matrix analysis of conditions based on information / data received from local government partners (local communities & authorities, union of municipalities) participating in the project. Expert discussion using the Delphi method.
Schedule: the months of May – June 2023.

2.3.2 Analysis and assessment of the importance of the various identified determinants of citizens engagement of households in undertaking practices for activities in a given CSS

In this activity, a descriptive analysis (assessment) of the relevance of the various identified determinants that affect households' uptake of the practices identified in Section 5.2.1 and 5.2.2 for CSS will be made. The analysis will be used to develop a summary that identifies key determinants of the effectiveness of households' undertaking practices relevant to the implementation of CSS activities. Recognition of these conditions, and determinants will be necessary for the identification and, finally, programming (on a local / regional scale) of activities supporting households in their involvement in CSS 1 and the selection of instruments for this purpose (Section 5.3.3).

Methods of implementation: Expert discussion. Descriptive analysis of the study.

Schedule: May – June 2023.

2.3.3 Identification of instruments (tools) to support household practices in their commitment to activities within the framework of CSS1 "Wood Packaging"

The activity will include the initial identification, review and mapping of instruments that can potentially influence households to undertake the practices for implementation of CSS 4 identified in Section 5.2.1 and 5.2.2. The starting point for the selection of instruments is the analysis performed in Section 5.2.2. The logic diagram for such identification is presented in Table 19. This analysis will be performed separately for each CSS.

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Table 19: Flowchart for identifying / analyzing / evaluating instruments to support household practices for implementing solutions for each CSS (separately)

Instruments / tools to promote social engagement	**Name of practice (practice categories)**										
	Refusing	**reducing**	**reusing**	**refurbishing (renewal)**	**repairing (fixing)**	**repurposing**	**recycling (processing)**	**segregation and selective collection in the local waste management system**	**sharing**	**leasing (rental)**	**other practices specific to CSS**
Promotional activities/ initiatives											
Educational activities/ initiatives											
Information and consultancy activities/ initiatives											
Financial incentives (positive and negative)											
Legal and administrative regulations											
Co-creating solutions (consultations, workshops, forums, referenda)											
Self-regulation (voluntary regulation)											
Other (?)											

NOTE: the table is used to identify instruments to promote social engagement of households in undertaking practices for implementation of activities/solutions envisioned in a given CSS. Identification using scale:

- very important / key instruments (conditioning the effectiveness of CSS activities - essential),
- essential instruments (to support the effectiveness of CSS activities),
- Instruments generally supporting social commitment to CE,
- no relationship or marginal importance of a given instrument for undertaking practices in a particular area (no or insignificant impact on the implementation of activities under a given CSS).

Source: own study.

Methods of implementation: Matrix analysis based on the literature review and previous work provided for in this plan. Expert discussion using the Delphi method.
Schedule: June – August 2023.

2.3.4 Description of recommended instruments (tools) to support household practices in their commitment to activities within the framework of CSS1

The activity will carry out a descriptive conceptualization of the instruments that should be used at the level of the local/regional territorial system for supporting household practices (identified in Section 5.2.1 and 5.2.2), the undertaking of which will contribute to the

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implementation of the activities envisaged under the given CSS and increase community engagement in the CE in general. The starting point for the detailed characterization of the instruments is their preliminary overview made in Section 5.3.3. The description of the instruments should include their assignment to following subjects:

- municipal / community local governments,
- county local governments,
- regional local governments,
- non-governmental organizations (NGO’s),
- scientific and research entities, academic institutions,
- private entrepreneurs,
- public entrepreneurs,
- households,
- others (?).

Methods of implementation: Expert discussion. Descriptive analysis on the basis of literature review and previously performed work provided for in this plan.

Schedule: months of August – September 2023.

2.3.5 WP-specific activities implemented under the framework of CSS1

Within the framework of WP3, T.3.4 activities related to the dissemination of CSS1 technology in local communities covered by project activities are envisaged. The activities described in sections 5.3.2 and 5.3.3 will include informational and educational activities on the use of wood packaging waste.

Under Measure 5.3.5, the following activities will be conducted:

- analysis of the possibility of household engagement in the needs of wood packaging,
- analysis of the technological feasibility of using waste to create items useful to households,
- analysis of the possibility to create social enterprises in the CSS area.

Methods of implementation: focus research in the local community on the needs for the use of wood packingage, technological analysis, and expert discussion.

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Schedule: months November 2022 – October 2025.

2.4 Activities scheduled for the implementation of the citizen engagement plan in CSS1 "Wood Packaging"

Table 20 shows an overview of planned CSS1 activities related to citizen engagement in the form of a goal – implementation matrix.

Table 20: Activities planned for citizens' engagement in the implementation of CSS 1 "Wood Packaging"

Objective of activities	**Planned activities**	**Lead time**	**Contractor/leader**	**Place of implementation**
Identification of needs regarding the scope of social involvement of citizens (households) within a given CSS (1)	[5.2.1] Identification of the expected citizen (household) involvement for a given CSS	November 2022 – January 2023	OPUS	All technical partners under CSS 1
	[5.2.2] Characteristics of the specifics of the expected household practices identified for CSS 4	February – April 2023	OPUS	All technical partners under CSS 1
Identification and analysis of conditions and selection of instruments to support the social involvement of citizens within the CSS 1	[5.3.1] Identification of the determinants of social involvement of citizens (households) and the possibility of undertaking practices for activities in a given CSS	May – June 2023	OPUS	Activities planned for use in the region of Lodz and the municipality of Parzeczew and on the territory of the Bzura Intercommunal Union
	[5.3.2] Analysis/ assessment of the importance of the variously identified determinants of citizens' engagement of households in undertaking practices for activities in a given CSS	May – June 2023	OPUS	
	[5.3.3] Identification of instruments (tools) to support household practices in their commitment to activities within the framework of CSS1	June – August 2023	OPUS	
	[5.3.4] Description of recommended instruments (tools) to support household practices in their commitment to activities within the the framework of CSS 1	August – September 2023	OPUS	

Source: own compilation.

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The action plan for CSS 1 is linked to activities under WP7 where individual activities will be implemented in the form of community testing.

The complementary catalog of activities which are going to be launched under WP 7 framework are presented in Table 21.

Table 21: Catalog of complementary activities to be launched under WP 7 framework

Objective of activities	**Planned activities**	**Lead time**	**Contractor/Leader**	**Implementation sites**
Increase the knowledge of the region's residents concerning activities within the framework of CSS 1	Outreach activities: a) information campaigns on CSS 1, e.g., through traditional information channels (local media, social media); b) preparation of informational materials for residents in print and electronic form on CSS1 solutions (e.g. posters, podcasts, educational videos); c) creation/ establishing of a dedicated fanpage on the local community social media platform regarding all CSS; d) participation in local cultural events that will present the assumptions of the circular economy. circular economy.	December 2022 - March 2025	Veltha	Activities planned for use in the region of Lodz and the municipality of Parzeczew and on the territory of the Bzura Intercommunal Union
	Educational activities a) hybrid thematic seminars (online and onsite) on the use of, for example b) training on the implementation of circular economy goals and design objectives - applicable to all CSS, c) educational activities for kindergartens, schools, including competitions for children in the area of CSS1	December 2022 - March 2025	Veltha	Activities planned for use in the region of Lodz and the municipality of Parzęczew and on the territory of the Bzura Intercommunal Union
Increase engagement of residents in the activities within the framework of CSS 1	a) local micro-grant programs for residents to promote closed-loop economy solutions including those dedicated to CSS 1	December 2022 - March 2025	OPUS /municipality of Parzeczew/ ZMB	Activities planned for use in the region of Lodz and the municipality of Parzęczew and on the territory of the Bzura Intercommunal Union

Source: own compilation.

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3. Executive implementation plan

3.1 Gasifier delivery and commissioning

From the beginning of the project, BKT will design and build a biomass gasifier to be used during the demonstration of CSS1.

The air gasifier will be delivered to the site of UNIBZ by the end of July 2022 (expected date of delivery: 21st July 2022). UNIBZ has already coordinated the planning activities necessary to ensure a smooth delivery and site installation of the BKT plant, by involving appropriate carriers and construction operators for the displacement of the apparatus on site.

In the days following shortly the installation, the final commissioning operations will take place, including the connection of the plant to site utilities (electricity and water).

While UNIBZ staff will attend a preliminary training session at the BKT's premises during the period 11th – 14th July, a three-days full training will take place between the 21st and the 23rd of September at the UNIBZ site. During such training, BKT will demonstrate the startup and steady-state operation of the system in the presence of the attendees, that will include the UNIBZ staff, as well as delegates from NTUA and K-FLEX, if compatible with other existing commitments on their side.

In the interim, UNIBZ will carry out preparatory activities for the transformation of an initial batch of biomass fuel, that will serve the commissioning and plant testing operations. Such activities will involve the delivery of a load of residual pallets, supplied by a local waste management operator, that will be subsequently ground and pelletized according to the required fuel specifications indicated by BKT.

3.2 Demonstration for char production

The first part of the demonstration campaign will involve the production of high-quality char. UNIBZ staff will operate the gasifier with a specific focus on char production, thereby analyzing the mass yields of char and formulating and testing strategies to shift the overall carbon balance towards higher char yields, through a careful tuning of the gasifier operating parameters. The experimental routine will follow an iterative three-step procedure, comprising 1) the operation of the gasifier at the selected parameter values, 2) the evaluation of the carbon and mass balance achieved, 3) a new selection of operating parameters.

Char collected will be characterized both by UNIBZ and CERTH and its possible applications as additive for compost and filler/pigment for polymers will be assessed.

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UNIBZ will carry out proximate, ultimate, thermogravimetric and physisorption analysis, while CERTH will perform a detailed analysis of the contaminants in the char for its possible applications in agriculture and evaluate post-treatments if necessary.

Based on the characterization results, CERTH with the cooperation of UNIBZ will explore - in a simulation way - other potential pathways for char utilization such as hydrothermal liquefaction for advanced liquid biofuels synthesis or activated carbon production.

Although the Grant Agreement set the deadline for Task 3.2 - Gasification for char production at M18, partners would like to postpone it to M32 to ensure not only good quality results, but also a exhaustive and precise evaluation of char applications.

3.3 Demonstration for syngas utilization and post-combustion carbon capture (PCC)

3.3.1 Syngas combustion (UNIBZ)

The demonstration of syngas combustion will entail the design, procurement, and installation of an experimental combustor. The design activities will start in August 2022, and procurement will follow. Assembly and installation will take place by January 2023.

Experimental activities on syngas combustion and flame testing will thus start in February 2023 and meet completion by July 2023. The planned schedule will allow for a two-month window during which the gasification system will be decommissioned from the UNIBZ premises, picked up and shipped to Athens, and, once there, re-installed and commissioned by BKT. The allowed time is considered sufficient to withstand any unforeseen malfunctioning of the plant that may require repairs ahead of relocation to Athens.

The experimental work carried out at UNIBZ will be accompanied by a close communication with the NTUA team relatively to the ongoing results obtained during combustion operations. Such information will serve possible revisions in the design and assembly of the combustion equipment, as well as the design of the carbon absorption unit to be installed at NTUA.

3.3.2 Gasification setup relocation to Athens

Prior to further experimental activities, the gasification system will have to be relocated from UNIBZ (Bolzano, IT), to NTUA (Athens, GR). Such relocation will have to take place by October 2023, to allow for a timely installation on the new site. Starting approximately in April 2023, UNIBZ and BKT staff will coordinate with NTUA staff to arrange and schedule plant transfer operations. Such arrangements will include the communication of specifications relevant to pick-up, such as dimensions and weights, and the facilitation of

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agreements between NTUA and local carriers in Italy. Based on present projections, the system will be traveling to Athens during the month of September 2023.

3.3.3 Syngas combustion and PCC (NTUA)

Demonstration of CH4/syngas mixtures combustion will entail the modifications of existing NG boiler/burner, the procurement of the required equipment and the development of an integrated system (gasifier-boiler) for combustion. A gas mixing station will also be installed in NTUA LSBTP premises for the purposes of the Frontsh1p project. Investigations into boiler modifications and optimal configurations as well as research for the gas mixing station began in September 2022. Procurement of the required equipment will follow. Suggestions for burner modifications will also be expected from UNIBZ. As mentioned above, the experimental work carried out at UNIBZ will be accompanied by a close communication with the NTUA team and results obtained during combustion operations will serve as possible revisions in the design and assembly of the combustion equipment. Furthermore, NTUA will perform tests on the modified boiler with NG/syngas mixtures before the gasifier arrives in NTUA premises to make sure the combustion system will operate properly. In this case, a gas mixing station will be used to supply the boiler with gases that replicate the syngas produced in the gasifier.

Demonstration of Post-Combustion CO_2 Capture will entail the design and installation of a compact PCC unit operating with appropriate solvents for CO_2 capture (MDEA, MEA or potassium carbonate (K_2CO_3)). Thermodynamic models for the absorption/desorption process have already been developed in Aspen Plus, using MDEA and K_2CO_3 as solvent for larger scale PCC. Modifying the thermodynamic models in proper scale as well as column sizing will begin in November 2023. Design activities of the compact PCC unit will begin in January 2023, and procurement of the required equipment will follow. Product gas treatment, solvent tank, rich and lean gas intermediate tanks, cross flow heat exchanges, two feed pumps for lean and clean solvent, two recirculating pumps as well as a reboiler unit will be integrated in the compact post combustion capture unit.

Demonstration of the integrated system (gasifier-boiler-PCC) will entail the coupling of the separate systems to validate the overall bio-syngas production and utilization in industrial boiler with PC. The operation mapping, the optimised parameters, the configurations for industrial technology deployment and the optimum management of the overall process will be defined after the tests on the integrated systema and should be expected no later than August 2024. The requirements for gas treatment in the integrated system will be investigated and pipelines for the interconnections will be built and insulated. The development of the integrated system will begin after all separate systems have been installed in NTUA premises and operating properly and should meet completion by February 2024. Thus, tests of the overall system will begin on/after April 2024. The allowed time is

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considered sufficient to withstand any unforeseen malfunctioning of the integrated system that may require repairs. Based on present projections, the system will be traveling to Lodz during the month of September/October 2024. NTUA, BKT and K-FLEX teams will be in communication to arrange and schedule the plant transfer operations according to schedule.

3.4 Final demonstrative setup at K-FLEX

3.4.1 Setup relocation to Lodz

The gasification system will be transferred to the K-FLEX site by October 2024. Site preparation activities will take place prior to that, and it is expected that within one month (November 2024) site integration activities will be completed, including the connection of outlet gas lines and heat transfer lines. The gasifier will then be fully operational and tested with the use of residual wood obtained from pallets at their end of life.

3.4.2 Operation at K-FLEX

K-FLEX will evaluate the possibility to gasify the mentioned wood residues to produce syngas that will combusted to provide heat for the normal industrial operations and its connection to a post-combustion carbon capture unit for the provision of high-quality CO2 to be used in supercritical treatment processes on site.

3.5 Ecodesign and circular economy business models for CSS1

This task is led by NTUA, who will carry out a Life Cycle Assessment (LCA) and Social Life Cycle Assessment (S-LCA) study of the CSS1, forming case studies involving industry, residential heating and chemical recovery plants, as well as a Life Cycle Cost (LCC) analysis to assess the CSS1 economic viability. In addition, sensitivity analysis will also be conducted, identifying environmental "hotspots" in the CSS1 technological pathway. The analysis results will serve as the basis for proposing configurations in the supply chain to reduce its environmental impact. The Goal of this study is the identification of potential, as well as existing, value chains based on wood packaging re-use or recycle, using the procedure co-created and validated by the 17 EU regions (including Lodz).

LCA is nowadays considered the most powerful and effective tool for comparing the environmental impacts of products, technologies and services with a view to either the whole life cycle (cradle-to-grave) or a targeted part of the life cycle (cradle-to-gate, gate-to-gate, gate-to-grave). LCA as a process evaluates the effect that a product has on the environment over its lifetime, as the means to increase resource-use efficiency and decrease liabilities. In that sense, LCA provides a tool for supporting environmental decisions. In the same principle, S-LCA and LCC examines the impact of a product's life cycle in terms of the societal effects

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on the communities and the economic effects and viability of the value chain, highlighting economic "hotspots" to be re-evaluated by decision-makers.

LCA is a well-defined and standardized methodology, in accordance with the 14040:2006 - Environmental Management - Life Cycle Assessment - Principles and Framework and 14044:2006/A1:2018 - Environmental Management – Life Cycle Assessment — Requirements and Guidelines (based on ISO 14044:2006/Amd 1:2017) and the International Life Cycle Data (ILCD) Handbook. The ILCD Handbook further specifies the provisions of ISO 14040 and 14044 standards on environmental LCA.

3.5.1 Implementation Plan

The goal of this study is the evaluation and communication of potential impacts for the proposed CSS1.

The first step for the LCA implementation is the definition of the product system and system boundaries. To deliver the LCA/LCC/S-LCA framework for the study, NTUA will review the outcomes of the previous tasks within Work Package 3 (WP3) and establish a baseline scenario.

Identification of the system boundaries is an essential part of the LCA scoping phase. ISO standard 14044 defines the system boundaries as the "set of criteria specifying which unit processes are part of a product system", where a unit process is the "smallest element considered in the life cycle inventory analysis for which input and output data are quantified". Selected boundaries of the system are chosen to effectively support the study's goal and ensure that the results comprehensively characterize the product's life cycle.

The next step is the definition of the Functional Unit (FU) for which the environmental impact will be evaluated. FU stands as the quantified product of the system to which environmental, societal and economic impact will be connected.

In accordance with the ISO 14044 (2006), following the definition of the system boundaries and the FU, several cut-off criteria will be used, as to decide the inputs that will be considered in the assessment, such as mass, energy and environmental significance. Such criteria will enable the system's simplification and LCA/S-LCA/LCC implementation while maintaining the results' quality.

The next step of implementation concerns the allocation procedure. In case of a multi-functional system, where many products are delivered as the system's output, the "Allocation" LCI procedure will be applied according to the ISO 14044:2006.

Following the conclusive definition of the goal and scope of the LCA, the impact categories under consideration will be defined, such as Global Warming Potential (GWP 100 years).

After definition of the goal and scope and the impact categories to be considered, LCI data will be gathered to perform the impact assessment. Such data will concern:

- Material inputs, including major and auxiliary materials,
- Water inputs,

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- Energy inputs, including all fossil fuels, non-fossil fuels, electricity, and purchased thermal energy,
- Product, intermediate product and by-product outputs,
- Environmental releases such as air, water and solid waste releases,
- Waste treatment mechanism (e.g., treated, non-treated, recycled, landfilled, etc.),
- Processes description at the various production stages included in the system,
- Information for the Plant,
- Source of major and auxiliary materials,
- Information on the transportation inside the system boundaries (e.g., type of transportation, distances, energy type and consumption, etc.)

LCI data will be collected by measurements from the pilot sites, as to ensure that the database constructed will be as technologically representative as possible. In this direction, NTUA will initiate the construction of an LCI data collection questionnaire to be distributed to the project partners involved. In case of data missing, the information required will be obtained by other sources.

Besides data from the sites obtained by the questionnaires, integrated databases in GaBi for raw materials, wastes, products and processes (Ecoinvent, ELCD of EC-Joint Research Center and others) will be utilized as data source. Datasets provided by GaBi will be evaluated concerning their applicability in this specific study and utilized accordingly. Data within GaBi are primarily gathered by industrial measurements and thus are considered technologically representative and up-to-date.

Modelling and developing of the system and the LCI database will be done using the GaBi commercial software package. The finalized LCI data will be a mixture of measured, calculated or estimated data, deriving from real stream analyses through measurements and characterization, GaBi database, modelling results and actual demo plant performance (power consumption, mass and energy balances etc.), relying heavily to the data acquired from the questionnaires.

To achieve this, NTUA will also provide a detailed time plan for remote interviews and meetings with partners for data collection. Such an action will facilitate the construction of a concrete LCI database, acquiring previously missing information and ensuring the data is up-to-date.

Following collection, a detailed review of all the info available and related to the CSS1 LCA/S-LCA and LCC will be conducted, to assess its quality and adequacy.

In general, the LCI phase will be implemented in three steps including: a) Process steps description, b) Data collection and c) System modelling. After construction of the system model and LCI database, the LCIA results for the defined impact categories will be calculated, evaluated and lastly interpretated. LCIA interpretation concerns the identification of significant issues of the analysis, environmental "hotspots" of the system to be evaluated, conclusions for the system's viability and essentially constitutes the final product of the study.

During the implementation period, at least two meeting with WP partners will take place concerning the preparatory actions for the LCA/S-LCA and LCC as well as reviewing the final

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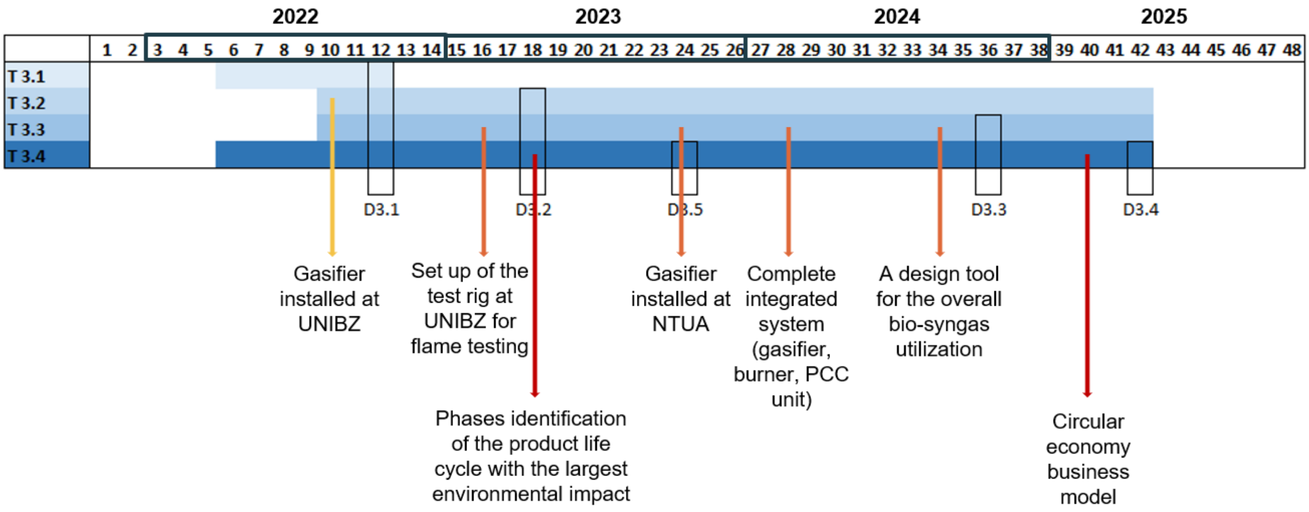
decisions of implementation. NTUA will also conduct an internal report, to be updated every six months, concerning the study's approach and methods, as to facilitate the actions and progress tracking, moving towards the LCA/LCC/S-LCA final report.
Based on the results of the LCA/S-LCA and LCC analysis, a circular economy business model will be proposed, in respect with the particular needs and expectations on the stakeholders involved, concerning the environmental impact, economic viability etc.

3.6 Gantt chart

Figure 7 shows the Gantt chart of WP3 where task durations, project deliverable deadlines and WP3 fictitious deadlines are reported.

Figure 7: Gantt chart of WP3



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