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CELEBio

D2.1

Country report: Croatia

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Publishable executive summary in national language	Izvješće o dionicima bioekonomije u Hrvatskoj predstavlja pregled svih dionika i skupina dionika koji moraju biti uključeni prilikom postavljanja lanaca dobave i korištenja biomase. Izvješće je prikazano kroz 9 poglavlja, unutar kojih su dionici raspodijeljeni u sklopu sektora poljoprivrede, šumarstva, otpada i ribarstva, bio-bazirane industrije, dionika u sektoru edukacije, javnih tijela te financijskih institucija. Svaki sektor je kratko opisan te su definirani glavni dionici, uključujući i kratak opis njihovih aktivnosti.

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Table of Contents

This project received funding from the BBI JU under the EU Horizon 2020 research and innovation programme under grant agreement No.838087

This project received funding from the BBI JU under the EU Horizon 2020 research and innovation programme under grant agreement No.838087

Table of Illustrations

FIGURES

TABLES

This project received funding from the BBI JU under the EU Horizon 2020 research and innovation programme under grant agreement No.838087

Summary

The main objective of CELEBio is to contribute to strengthening Bioeconomy-related activities in Bulgaria, Czech Republic, Croatia, Hungary, Slovak Republic, Slovenia and the neighbouring countries. This report aims to provide the necessary background information needed to evaluate the possibilities for setting up bio-based production chains in three different sectors: agriculture, forestry and waste management in Croatia.

Croatia is a small country in the EU according to land surface with 4 million inhabitants, with over 60% living in the rural areas, and around 20% living in urban areas. However, there is a threat of the outflow of skilled labour, which in turn has a negative impact on economic performance and the economic situation in general.

Forest area makes up 40% of Croatia's land area, which is mostly located in the central and northern parts of the country. Agricultural land makes up 27% of the land area, mostly in the southern parts of the country with a typical Mediterranean agriculture and on the North, grain and industrial crops (sugar beet, oil crops) and vineyards.

Croatia is a significant part of Trans-European Transport Network (TEN-T), with 6 important coastal ports and a significant potential within inland marine ports. Its strategic geographical position is exceptionally favourable for supplying markets in Central and Eastern Europe and has a high impact on markets as a leader in the Balkan area. The aforementioned ports are well connected with railway and especially the road network. Furthermore, the energy sector is well connected all along the country, but also with neighbouring countries through the transmission network.

Agricultural biomass production, harvesting and collection in Croatia is a challenge for various reasons: bulkiness, dispersed production, considerable amounts of water in the biomass, etc. The concept of bio-hubs came to life only in Istria, where local farmers are currently in the process of setting up a hub. However, biomass from agricultural sector in Croatia has a large potential for future development (e.g. unused potential available from primary residues, secondary residues and unused lands), but there are also several threats to this development (e.g. lack of market for high added value biomass).

Regarding forestry sector, Croatia has a relatively large forest potential for the small-sized country it is. Forests are considered as one of the most important resources for Croatian economy, both as energy source and feedstock for wood processing industry. Forestry and wood processing sectors have a long tradition and are well developed. However, statistical data are sometimes weak or contradictory, especially in the case of fuelwood and wood residues from wood processing industry. Moreover, it is necessary to improve infrastructure to mobilise biomass in areas that are more remote and establish a group of private forest owners to manage their land more successfully.

Waste management sector in Croatia is improving each year (amounts sent to landfills decrease and reuse and recovery of waste increase), however, the progress is very slow. Moreover, raw materials are lost with lack of energy and material recovery systems. Generated waste is treated in various ways, but the largest share is still going to landfill. Biodegradable waste is treated through landfilling, anaerobic digestion and composting. Based on the presented data, it can be seen that one of the strengths of waste management is the amount of waste generated, i.e. landfilled – therefore, usable for utilization. However, due to lack of knowledge on Bioeconomy principles and its possibilities, a significant amount of waste that could be energy/materially recovered ends up unused. Moreover, the public awareness on waste management is very poor.

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Although current bio-based industry is relatively small and there is no Bioeconomy strategy, Croatia has great potential to foster bioeconomy development. With a strong foothold in wood processing and food and beverage industry, there is room for significant innovation activities and new business models. In order to utilize the opportunities and potentials available in the country, Ministry of Agriculture took the lead in the development of Bioeconomy Strategy and Action Plan, which are expected to be adopted by spring 2021. These documents will encompass the regulations, strategic goals and priorities that are already existing in different national strategies, taking into account the financing aspect (business development, etc.), which is currently relatively slow due to the inefficiency of bureaucracy.

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1. Introduction

This chapter gives an overview of the objectives and approach of the CELEBIO Project and will directly pinpoint to the key and most typical characteristics of the country.

1.1. Objectives and approach

The main objective of CELEBio is to contribute to strengthening Bioeconomy-related activities in Bulgaria, Czech Republic, Croatia, Hungary, Slovak Republic, Slovenia and the neighbouring countries. To this end one of the key activities is to develop seven comprehensive reports for the target countries and the wider neighbouring region on the availability of sustainable biomass, logistics, costs and biomass business opportunities assessed through an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT).

This report aims to provide the necessary background information needed to evaluate the possibilities for setting up bio-based production chains in Croatia.

The information structure and analysis presented in this report was developed by building on the method designed and applied by Van Dam et al. (2014) and was further refined through the execution of interviews with bio-based business developers and other experts. In these interviews further information was obtained on key factors that guide the choice of setting up bio-based activities in countries. Most of the experts stressed that all the identified factors are important and that a system approach is key in developing bio-based initiatives. If one link in the chain is missing, the bio-based initiative will not succeed. The identified factors are mapped in this report and will be the basis for performing a SWOT analysis for development of bio-based production chains.

In Annex 1, a further explanation is given of the approach used to set-up this country report and the main interview outcomes with experts interviewed to refine the approach.

1.2. Reading guide

This report is organised in 9 chapters. In Chapter 1 (section 1.3) a first description is given of the key characteristics of the country of Croatia.

In the Chapters 2, 3 and 4 the biomass production, including their current uses and opportunities for what biomass can be additionally mobilised, is summarized for the agricultural, forest and waste sectors, respectively. First the main traditional production and availability of biomass for food, feed, forest biomass and wood products are discussed and how this is handled in further processing industries and/or used for domestic markets and exports. Subsequently an overview is given of additional biomass potentials that are likely to still be unused or only partly used and that are a good basis for development of new bio-based activities.

In Chapter 5 a description is given of the current bio-based industries and markets, advanced bio-based initiatives, and future biomass valorisation options.

In Chapter 6 the infrastructure, logistics and energy sector are described.

Chapter 7 focusses on the innovation potential, particularly in the context of bio-based research and development options. The research and educational infrastructure are described and the potential for developing bio-based start-ups and Public-Private-partnerships will be discussed.

Chapter 8 focusses on the policy framework and describes extensively what regulations, legislation, taxes and tariffs exist of relevance for the development of bio-based production chains. Attention will also be paid to situations where regulation and support measures are actually missing, and to which extend the rule of law situation influences the establishment of new bio-based activities.

In Chapter 9 potential financing options related to the development of bio-based production chains are discussed.

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1.3. Short characterisation of country

Croatia is a small country in the EU according to land surface with 4 million inhabitants (See Table 1). The average income level is relatively low in comparison to the average of the EU. The export value expressed in €/capita is still relatively low.

Table 1 Main population, land surface, GDP and trade characteristics of Croatia benchmarked against EU average

Category	Croatia	EU	Unit
Population	4.1	512.4	million (2018)
Area (total)	6	447	million ha (2018)
% population in urban areas	19.6	44.9	% of total population (2018)
% territory predominantly rural	62.9	43.8	% of total territory (2018)
% territory predominantly urban	1.1	10.7%	% of total territory (2018)
Agricultural Area	1.6	173.3	million ha (2016)
Forest area	2.5	164.8	million ha (2016)
Population density	73	115	n°/km² (2018)
Agricultural Area per capita	0.38	0.34	ha/capita (2016)
Forest area per capita	0.62	0.32	ha/capita (2016)
GDP/capita	12,588	30,956	at current prices in 2018
	19,275	30,956	GDP at purchasing power in 2018
GVA by Agriculture, forestry and fishing	3.6	1.6	% of total GVA (2018)

GDP = Gross Domestic Product; GVA = Gross Value Added
Source: Eurostat most recent statistical data sources (Accessed August/September 2019) (https://ec.europa.eu/eurostat/data/database)

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With the Adriatic Sea on the east (border with Italy), Croatia is surrounded in the North with Slovenia and Hungary, and in West with Serbia and Southwest with Bosnia and Herzegovina.

Over 60% of the Croatian population lives in rural areas, which is relatively high compared to the rest of Europe. Only close to 20% of the population lives in urban areas (Table 1), which is relatively high considering that only 1% of the land area is predominantly urban. The population density is also lower than the European average, and the GDP is significantly lower. Gross value added by agriculture, forestry and fishing is more than twice that of the European average.

Croatia's 5 largest urban centres are Zagreb, Split, Rijeka, Osijek, Zadar with 0.79; 0.18; 0.13; 0.11 and 0.08 million inhabitants.

Forest area makes up 40% of Croatia's land area, which is mostly located in the central and northern parts of the country. Agricultural land makes up 27% of the land area, mostly in the southern parts of the country with a typical Mediterranean agriculture and on the North, grain and industrial crops (sugar beet, oil crops) and vineyards. North to South road infrastructure is well defined with modern and fast highways from Zagreb to all end points of Croatia: Dubrovnik and Ploče (industrial port), Rijeka (port), Istria to Italy and Slovenia, Osijek to Danube (port) and Serbia, and to Varaždin and Hungary (Figure 1 and Figure 2). Train infrastructure needs modernisation but is well interconnected.

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Figure 1 Major transportation routes in Croatia (source: Ministry of Transport, Republic of Croatia)

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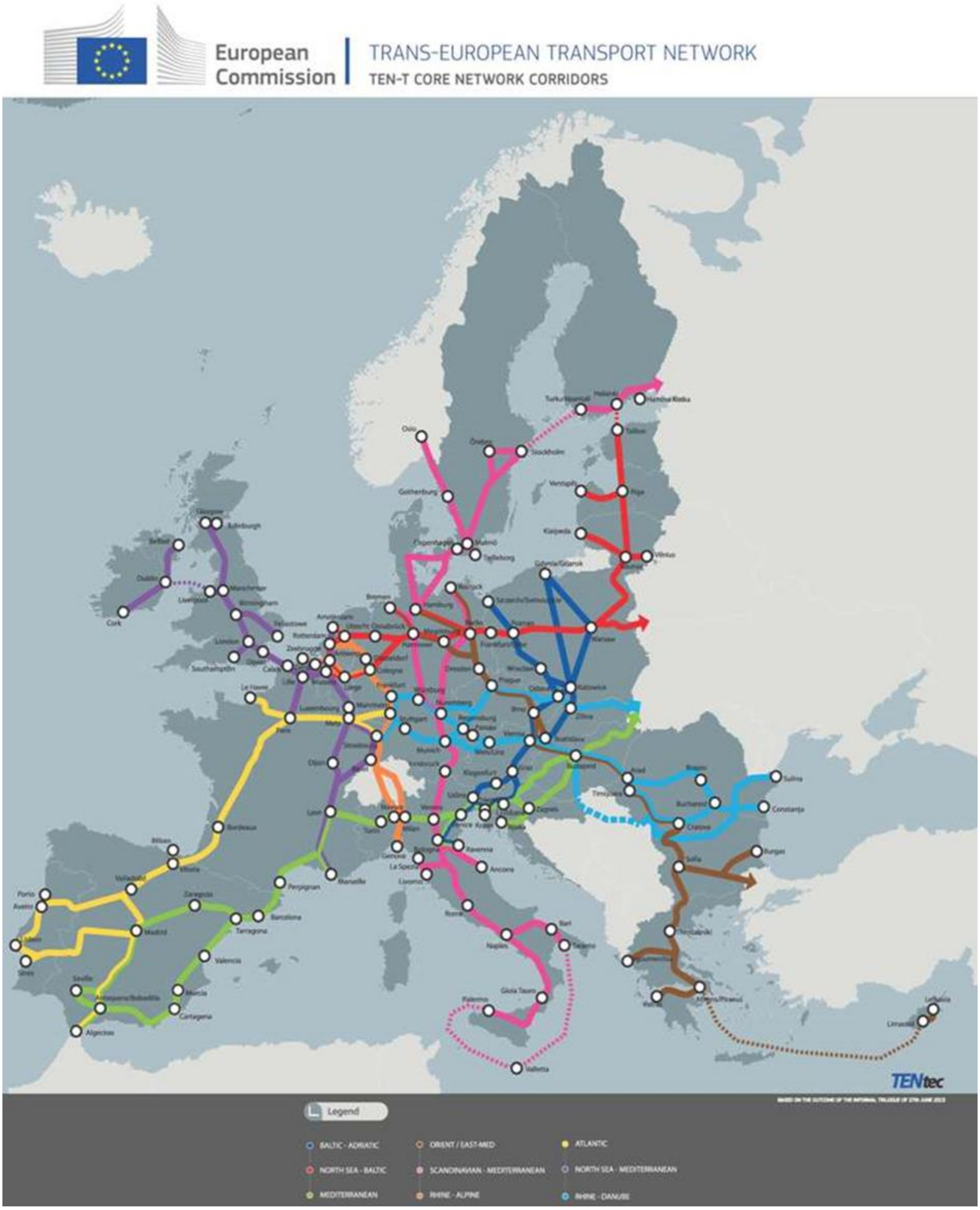

Figure 2 Position of Croatia in the Trans-European Transportation Network

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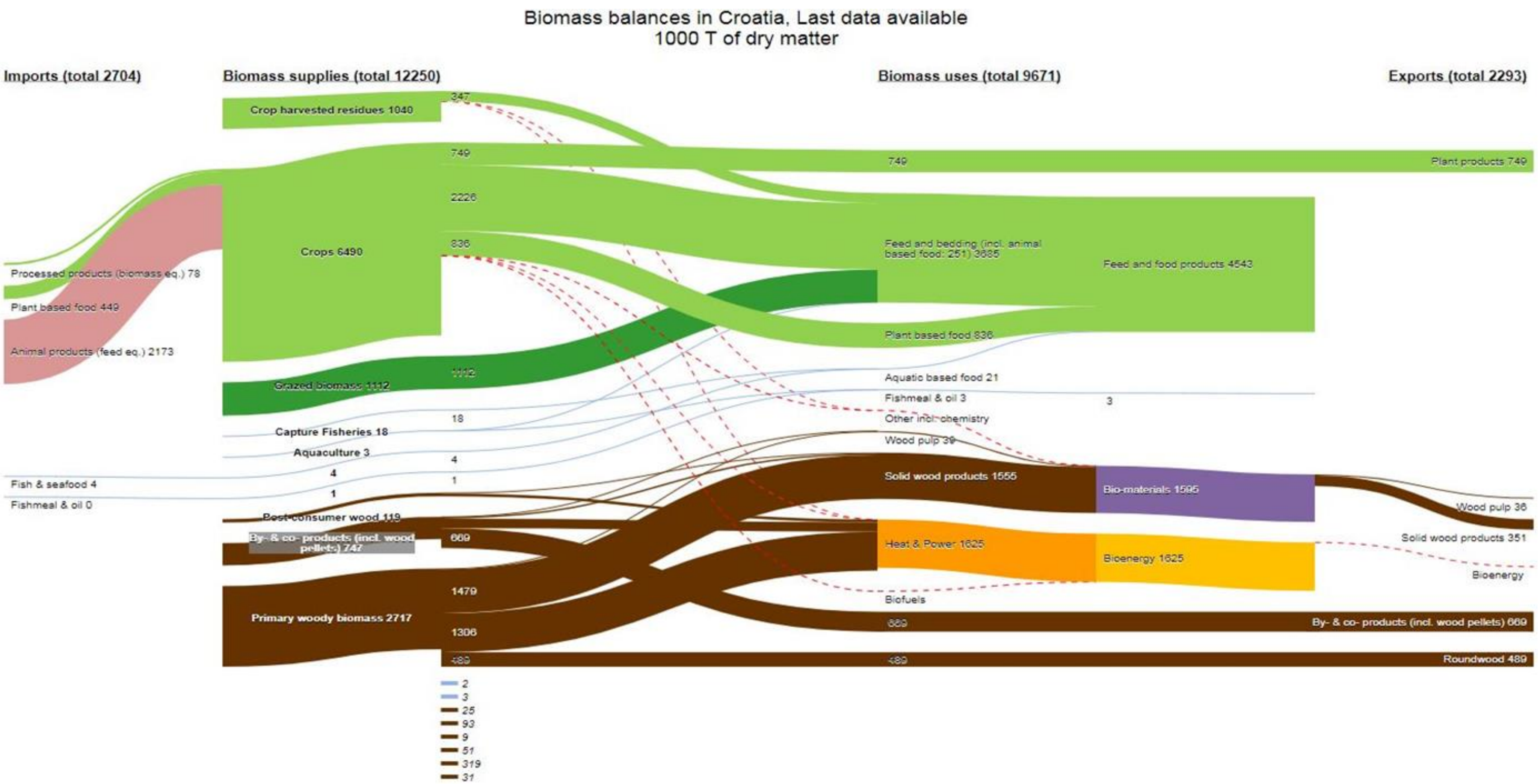

Figure 3 Biomass flows in Croatia (net trade), JRC Sanky Diagrams of biomass flows (Albusac et al., 2017: https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml

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Explanation of Sankey diagram (Figure 3):

the Sankey biomass diagram is split into biomass supply (shown on the left of the diagram) and biomass uses (right portion of the diagram). Each of these areas shows different categories: agriculture, forestry and fishery (supply), as well as feed and food, biomaterials, bioenergy, and direct exports for each sector (uses). All supply and uses of biomass have been converted to Ktonnes dry mass before integrating in the diagram. It is important to know that some of the components of the diagram will be missing for a certain country and/or year if the corresponding data has been reported as zero. This implies that the flow data should be interpreted with care as not all diagrams cover all biomass supply and/or use categories present.

Further information on the method and source data in: https://publications.europa.eu/en/publication-detail/-/publication/a19750d4-5498-11e7-a5ca-01aa75ed71a1/language-en

From the Sankey diagram for Croatia (Figure 3) the following main observations can be made (quantities below are all expressed in million tonnes of dry matter). The main biomass supply produced in Croatia is from crops (6.49), grazed biomass (1.11) and primary woody biomass from forests (2.71). Most of the cropped and grazed biomass is used for food and feed production (4.54); and the woody biomass is converted to heat and power (1.63), and solid wood products (1.55). The largest export volume are plant products (0.75) and solid wood products (0.35). Imports consist mostly in volume of animal products (2.17).

The production of biomaterials and bioenergy is much smaller than food, feed and plant products. Bioenergy is produced in combined heat and power plants (CHPs) on biogas (46.42 MW in 41 plants[1]) and solid biomass (70.71 MW in 33 plants1). Waste streams are slowly but steadily entering biogas feedstocks and pushing out maize silage (Figure 4). Very little solid biofuels are produced from crop residues in terms of agropellets (50 t/year capacity in 2018). Croatia holds 1% of the world's total pellet production and 3% of the total EU28 exports in 2016 (AEBIOM, 2017). Annual production of wooden pellets is 315,370 t/year production or 77% of the production capacities (EIHP, 2017), where only 15% stays for domestic consumption. The pellets are made both from primary and secondary residues, where secondary residues prevail.

[1] Croatian Energy Market Operator, data from August 2019.

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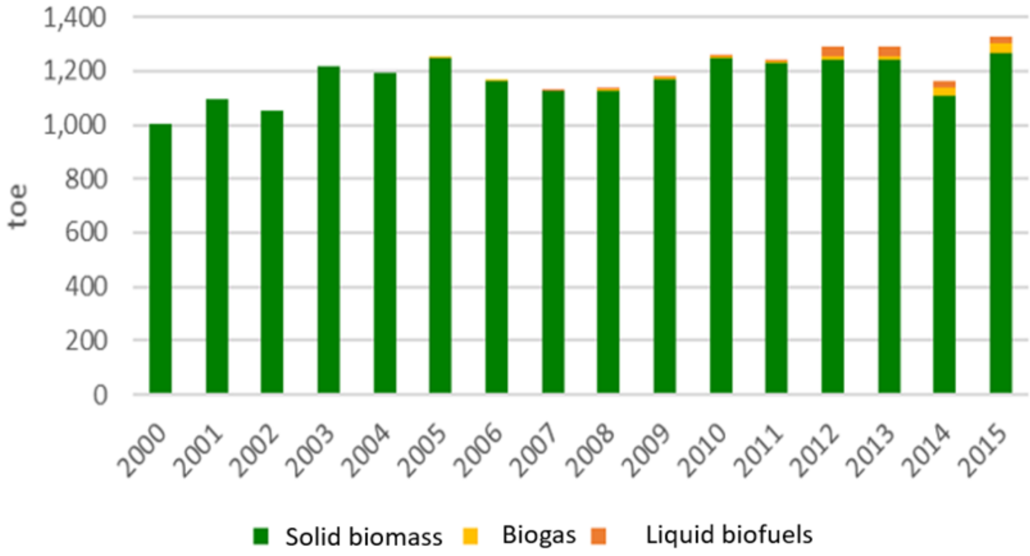

Figure 4 Production of solid, gaseous and liquid biofuels in Croatia (EIHP, 2017)

Croatian Sankey is very similar proportionally to the EU Sankey in terms of biomass production, but it differs greatly by imports of biomass (2,704) which amounts ~40% of the plant-based biomass produced within the country. This reflects poor productivity and room for improvement of the national biomass supply. In terms of biomass uses, there are also many similarities except that Croatia uses much less wood pulp, and a lot of the woody biomass is exported. Whereas EU-total records exports of animal produce which generate a high added-value, the export from Croatia is dominated by low added-value-commodities such as roundwood, primary plant products and wood pellets.

Food, beverage and tobacco contribution is about half of the total turnover, second by agriculture (Figure 5). While the turnover from food & beverage sector remained stable in absolute numbers, the turnover from agricultural sector is steadily reducing over the decade, ending up at 73% in 2017, in comparison to the 2008 turnover (Figure 6). The 3rd sector by the turnover is Wood and wooden furniture industry that recorded a 26% growth within a decade, but its overall contribution is at 11% in 2017. Similar patterns apply to the bio-based electricity that recorded 2,974% growth since the supporting framework for electricity from renewable energy sources was launched in 2007. The structure of the total turnover of bioeconomy indicates low productivity of bio-based sectors.

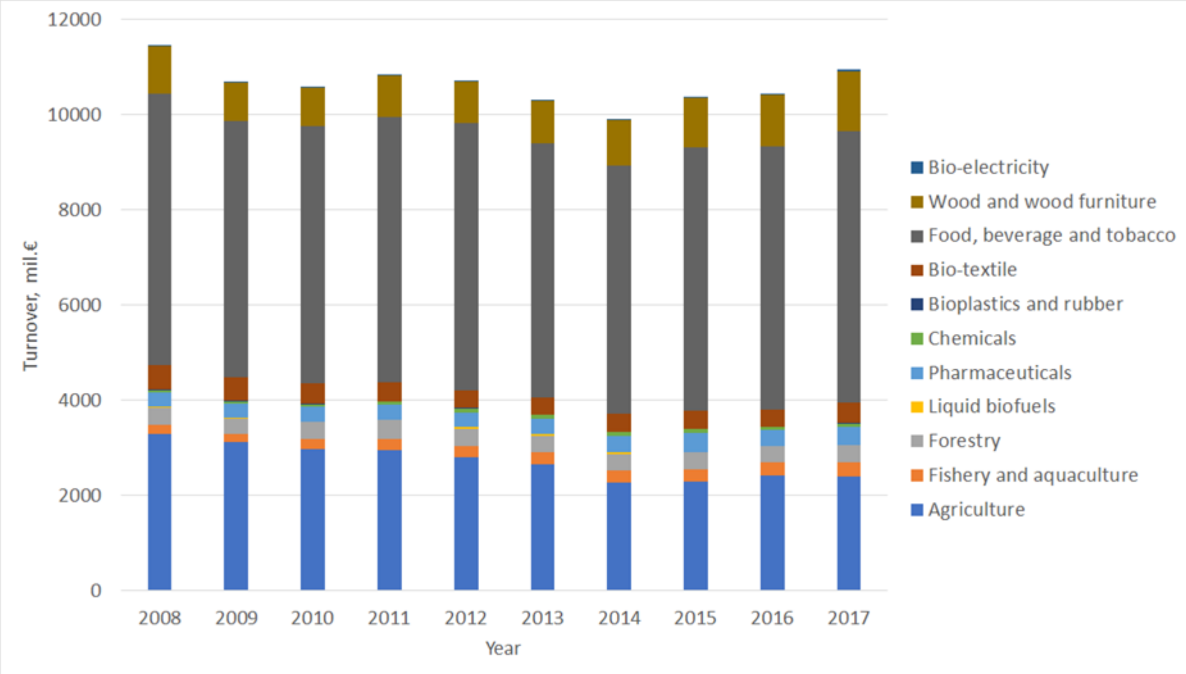

Figure 5 Timeline of bio-based sectors' turnover in Croatia (source: JRC, 2020)

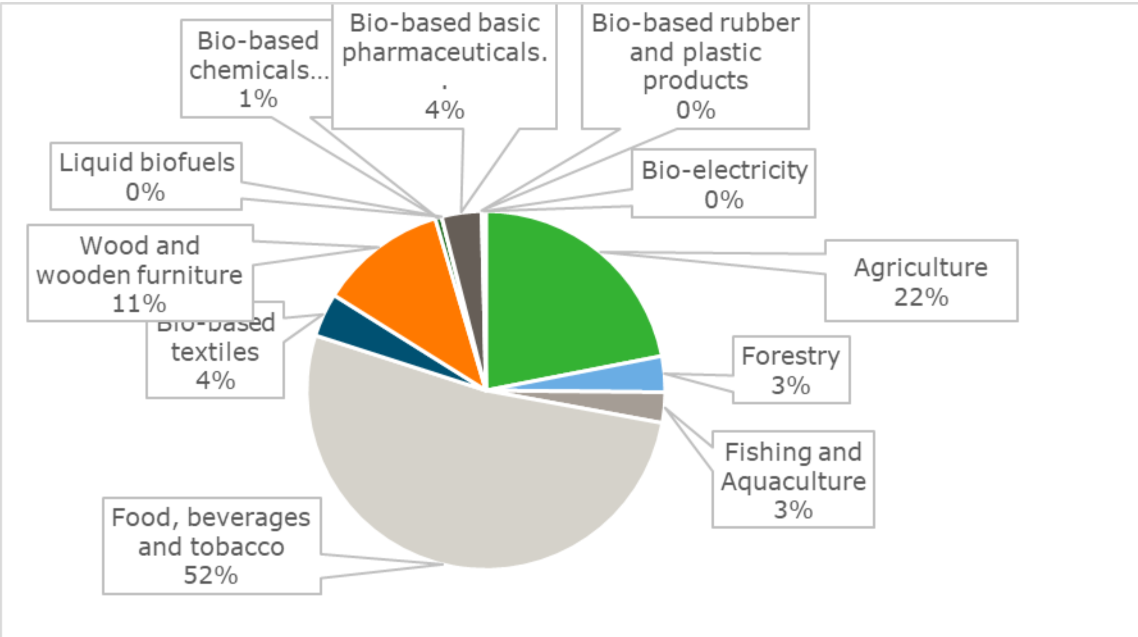

Figure 6 The structure of turnover from Croatian bio-based sector, 2017 (source: JRC, 2020)

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2. Biomass supply: Agriculture

2.1. Introduction

In this chapter the agricultural biomass production and main uses is described. A distinction will be made between the main economic products produced and their main process chains and residual biomass potentials from primary production and available as by-products of food processing industries. The residual biomass sources, certainly the ones from primary sources, are largely not used, as already became clear from Section 1.3. In addition to presenting the main biomass production, attention will also be paid to the importance and the structure of the agricultural sector and to the main environmental challenges associated with agriculture in Croatia.

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2.2. Characterisation of current agricultural sector

Croatia can be divided into three geographic and climate zones: the lowland with a continental climate in the north of the country, the Mediterranean coastal zone in the south, and the mountainous zone across the central part. With a varying climate, landforms and soils, the country is rich in biodiversity and is in a favourable position to produce a wide range of agricultural products, from field crops to grapes and continental and Mediterranean fruits and vegetables. Agriculture, forestry and fishing generate 3.5% of Croatian GDP. About 1.5 million hectares are utilised agricultural land, of which 54.5% refers to arable land and gardens; orchards, vineyards and olive groves occupy 4.7%, and permanent grasslands covering 40.6% of the used surface (Croatian Bureau of Statistics, 2018a) (Figure 7). Cereals and oilseeds are mainly cultivated in the Pannonian region, which covers 55% of the national territory and is characterized by moderately warm and humid climates (Croatian Chamber of Economy, 2017).

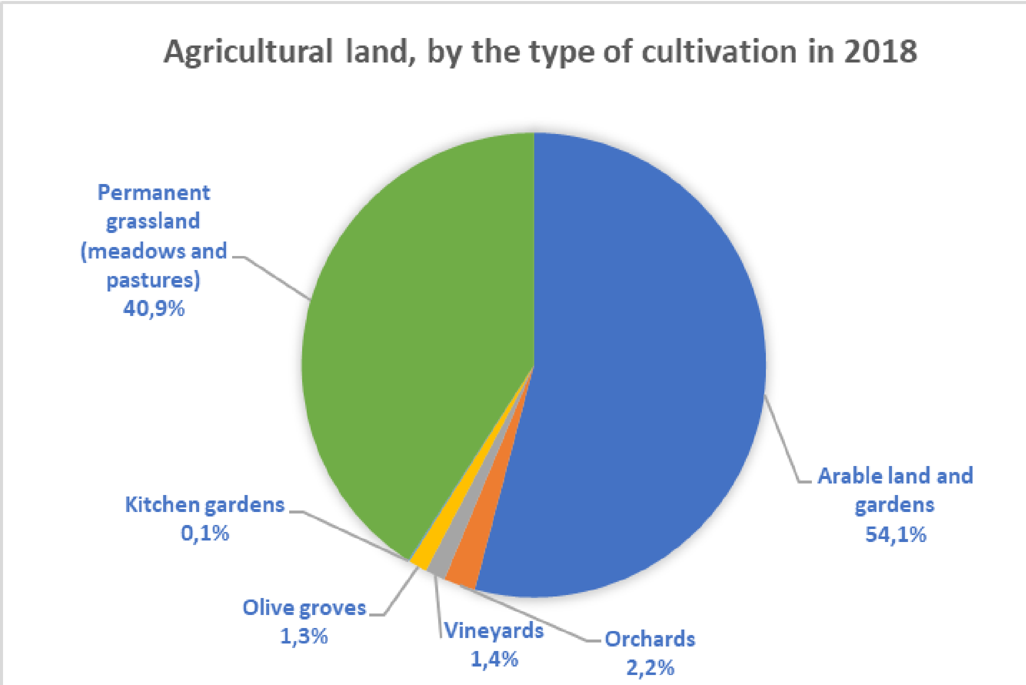

Figure 7 Agricultural land, by the type of cultivation in 2018 (Croatian Bureau of Statistics, 2018)

The average farm in Croatia uses 5.6 ha of agricultural land which is significantly less than the EU-27 average (on average 14.4 ha). The arable land of most farms is very fragmented and often distant from each other, which is one of the reasons for the inefficiency of agricultural production; in 2011, the agricultural production was carried out on an average of 15 cadastral parcels. Farms of up to 20 ha continue to dominate the structure of farms. According to the organizational form of farms in 2018, most farms operated as family farms (OPG), or as many as 162,248 (96.8%), with average size of 5.3 ha per farm. During 2018, Croatian farmers used a total of 1,133,851.8 ha of agricultural land. The holders of Croatian farms are older. As many as 63,208 farmers have holders over 65 years old (37.7% of the total number of farmers), while only 19,301 farmers have holders under 40 (11.5% in the total number of farmers) (Table 2).

Until 2014, no producer groups and organizations were registered in the Farm Register. The first producer group in Croatia was registered in March 2014 for milk producers. This situation of the small average farm size and organisational form of farms in Croatia indicates towards low economic sustainability.

Table 2 Key characteristics for the agricultural sector in Croatia

Category	Croatia	EU average	Unit
Agriculture in % of total employment	6.4	3.9	% of total employment 2017
Agricultural area per capita	0.38	0.34	ha/capita
Cereal yield	5.1	5.2	t/ha
Crop output in total output	60	56	% of total agricultural output value (2018)
Livestock output in total output	35	44	% of total agricultural output value (2018)
Agricultural income (2010=100)	119	121	Index 2010=100 (2018)
Livestock density		1.02	LSU/ha UAA
High input farms	29	29	%/total farms 2016
Low input farms	25	39	%/total farms 2016
Gross nutrient balance nitrogen	60	51	kg of nutrient per ha (average 2011- 2015)
Gross nutrient balance phosphorus	5	1	kg of nutrient per ha (average 2011- 2015)
Irrigated utilised agricultural area	1.0%	n.a.	% of UAA 2016
HNV farmland	90	41	% of agricultural land
Soil erosion	3.04	2.4	tonnes/ha/yr 2012
Average farm size	11.6	16.6	ha UAA/holding (2016)
% of agr. holdings < 5 ha	69.5	62.6	%/total no. of holdings

HNV = High Nature Value; LSU = livestock unit; UAA = utilised agricultural area (Source: S2BIOM, Benchmarking factsheets (https://s2biom.wenr.wur.nl/web/guest/data-downloads) updated with https://ec.europa.eu/agriculture/statistics/factsheets_en) and additional Eurostat data (https://ec.europa.eu/eurostat/web/agriculture/data/database))

The agricultural land per capita and agricultural employment in Croatia are slightly higher than the European average, although the ratio of agricultural land to total land area is similar. Croatia has slightly more high input farms (29%) than low input (25%); which is the reverse in Europe (29% vs 39%, respectively).

The Nitrogen (60 kg of nutrient per ha) and Phosphorus (5 kg of nutrient per ha) nutrient balances show relatively high losses as compared to the European average, which is likely related with relatively large differences between nutrient inputs and the nutrients that are removed by the crop with the harvest.

The share of agricultural land that is classified as High Nature Value farmland is extremely high which implies that Croatia still has large abundance of habitats and species with high nature conservation value in agricultural lands. These nature values depend for their conservation on a continuation of more traditional and low input farming systems.

Only 1% of the utilized agricultural area is irrigated, yet there is a high level of soil erosion due to wind and floods. There are slightly more farm holdings of <5 ha than the European average. In general, the soil quality is of good, and the farming conditions are relatively similar to the European averages.

Given the increasing challenges of agricultural production due to climate change, farmers need to think about how to maintain stable and sustainable agricultural production. Both current and new generations of farmers need to be educated to apply new practices, new technology and strike a balance between greater production and environmental protection. Education is key to spreading new knowledge and applying it. Also, negative agricultural practices in various aspects of agriculture can be mitigated through the proper education of all key stakeholders in the agricultural chain: from the primary producers to the end consumers.

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2.3. Crop production

When looking at the production of crops for existing food and feed uses, the Croatian production is in the lower position at the EU level with 3.8 million tonnes dry matter (d.m.) production (see Figure 7). The most important crops in Croatia are cereals and oil crops, e.g. sunflower and rape. Permanent crops cover an intermediate percentage age of the cropping area in comparison to the rest of the EU countries.

Total volume of gross agricultural production in 2018 increased by 5.0% compared to 2017. The growth in agricultural production in 2018 was affected by the growth in crop production, by 14.8%. In this type of production, most of the products with a larger share in crop production recorded a growth in production (e.g. maize by 37.7%, wheat by 8.5%, grapes by 25.7%, soya beans by 18.0%, etc.). Within gross agricultural production in 2018, crop production contributed with 59.1% and animal production with 40.9% (Croatian Bureau of Statistics, 2018b). In the period from 2013 to 2017, the harvested area and production of cereals decreased, while protein and oil crops showed a slight upward trend. According to the agricultural area utilized in the same period, maize is the most dominant crop in the Republic of Croatia, i.e. cereals. The productivity of crop production is relatively low, with average yields of basic crops below European levels. One of the key problems in crop production is insufficient adaptation to climate changes as well as market demand. For instance, irrigation, which, following frequent droughts on average every 3-5 years, results in significant crop damage and, depending on the intensity and duration of the drought, can reduce crop yields by 20-70%.

The underdevelopment of the water supply system on agricultural land is an additional factor supported by the fact that only 1.1% of the total utilized agricultural land is irrigated. Well-developed canal system was abandoned during the transition to the market economy. Most farmers do not have the opportunity to invest in irrigation infrastructure, and this risk is particularly evident during the summer months. Croatian agriculture is highly dependent on the weather, being the strongest reason of low agricultural output in crop production. The National Plan for Irrigation and Management of Agricultural Land and Water sets a target of 6% by 2020 (Ministry of Agriculture, 2013). In the light of climate changes, additional water consumption may have adverse effects on the ecological system. Good options for alleviation of water over-consumption is minimising the losses in the distribution system and developing highly efficient irrigation systems (i.e. drip or drop-by-drop irrigation systems). The other option would be to adapt cropping plans to novel climate conditions.

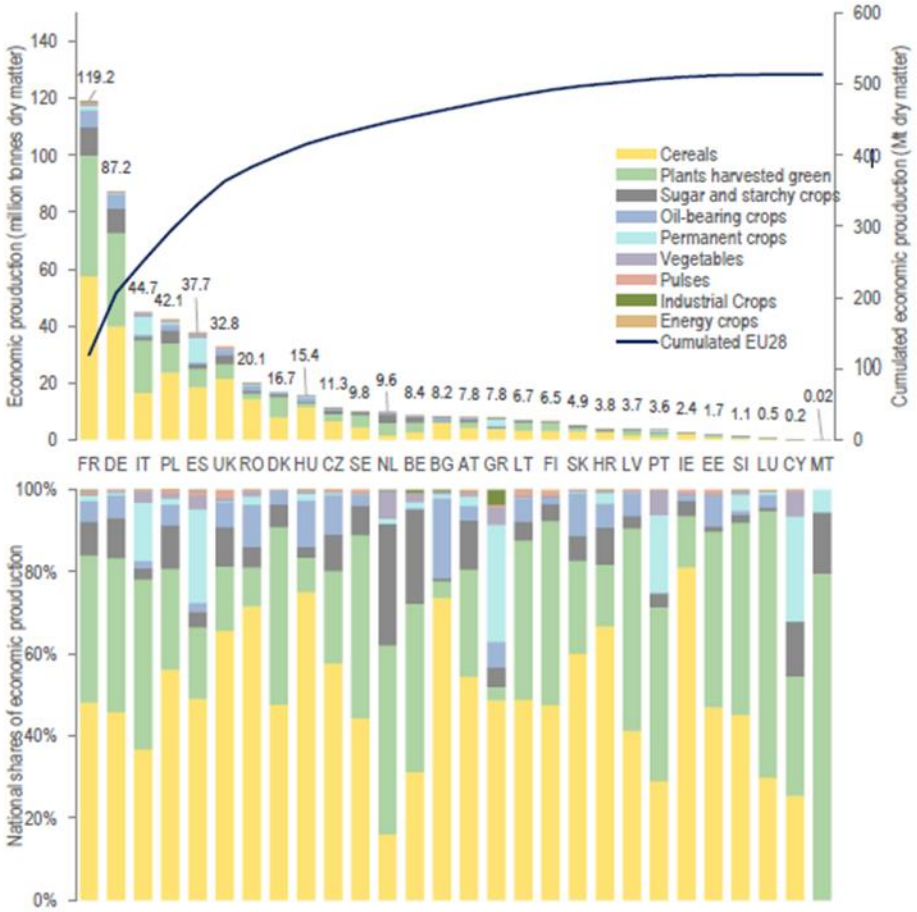

Figure 8 Economic production (top pane) from the main crop groups per member state, expressed in Mt of dry matter per year; and the shares at national level (bottom pane). Average values over the reference period 2006-2015. (Camia et al., 2018)

2.3.1. Cereals

In the period from 2010 to 2017, the total utilized agricultural area increased by 12% (from 1,333,835 ha to 1,496,663 ha) and cereal production decreased by 21% (from 584,663 ha to 461,483 ha). In the structure of cereal production, maize is predominant. In 2017, self-sufficiency in cereal production was 117.8%. In 2018, a total of 3,230,925 tonnes of grain was produced on a harvested area of 459,703 ha, with an average yield per hectare of 7 tonnes. The foreign trade of cereals generated a surplus. In 2018, cereals worth EUR 190.5 million were exported, while imports amounted to EUR 71.1 million resulting in a surplus of EUR 119.4 million.

Maize production in Croatia is directly influenced by global and climate trends. In the period from 2013 to 2017, maize is cultivated on an average of 260,819 ha, with the average year production over the five-year period of 1,868,920 tonnes. In 2018, 2,147,275 tonnes of maize were produced on 235,352 ha and the yield per hectare was 9.1 tonnes. Although Croatia's optimal geographical location for maize production with relatively fertile soils and a large selection of high-yielding hybrids, production differences can vary by more than 50% between years. The main reasons are insufficient rainfall during vegetation, uneven distribution of rainfall and extremely high temperatures in the phenological stages of flowering and fertilization. The lowest average yields were obtained in very dry years. In 2018, 516,694 tonnes of maize worth EUR 91.1 million were exported, while 41,309 tonnes of maize worth EUR 26.1 million were imported and a surplus of EUR 65 million was achieved.

It should be noted that the harvested areas refer to corn for the production of dry grain, while at the same time an average of 30,000 ha of silage maize is grown in Croatia (Iljkić et al., 2019; Zrakić et al., 2017). Production of silage maize in 2016 was carried out on 30,977 ha and a total of 1.3 mill. tonnes were produced. Due to the decreasing livestock number, maize silage growers opted for supplying biogas production. It has been estimated that some 700 Ktonnes of maize silage has been used for biogas production in 2018, harvested from 20,000 ha.

Wheat, in the period from 2013 to 2017, is cultivated on an average of 157,162 ha. In 2018, 135,708 ha were harvested, and 738,363 t of wheat was produced, and the yield was 5.4 tonnes per hectare. In the period of 2013 to 2017, 809,780 tonnes of wheat were produced annually on average, reducing production by 8.8% in 2018 compared to the five-year average. The impact of weather conditions on wheat yield is less compared to maize because it is a winter crop that is not so exposed to the effects of deficiency of precipitations and high temperatures. Wheat production shows a declining trend in utilized agricultural land (13.7% less in 2018 compared to the five-year average).

Barley, in the period of 2013 to 2017, also shows a declining trend in utilized agricultural land. In this five-year period, barley is in fourth place by utilized agricultural area, which was not the case earlier, while by production it is still in third place. Furthermore, barley was harvested on 50,818 ha with the production of an average of 218,795 tonnes. In 2018 barley was harvested on 50,988 ha which produced 227,520 t of barley, and the yield was 4.5 t per hectare. Due to the reduced harvested area, barley production in 2018 compared to the previous 2017 decreased by 12.6%. In 2018, 43,667 tonnes of barley worth EUR 7.7 million were exported, while 29,023 tonnes of barley worth EUR 6.9 million were imported, resulting in a surplus of EUR 871,368 (Ministry of agriculture, 2019).

Increase in the total volume of crop production in the overall structure of agricultural production after Croatia's accession to the European Union is a direct consequence of significant changes in the economic environment in which farmers currently find themselves. Given the positive production indicators, the domestic market is self-sufficient with cereals, especially wheat and maize, and since 2012 barley, except in years with extremely adverse climatic conditions. Croatia exports grain and creates positive net export values.

2.3.2. Oil crops

Compared to cereals, oilseeds, and especially soybeans and rapeseed, tend to grow in production areas. The most significant oilseeds in Croatia are soybean, sunflower and rapeseed. In the period from 2010 to 2017, in the total production of oilseeds, expressed in terms of quantity, soybean dominates (in the observed period soybeans make up 44.7% of total oilseed production), followed by sunflower (in the observed period sunflower accounts for 24.8% of total oilseed production), rapeseed (in the observed period rapeseed makes 15.9% total oilseed production) and sugar beets (in the observed period other oilseeds account for 15.0% of total oil production). In the same period, oil crops in the Republic of Croatia were on average annually produced on around 143,604 ha.

Soybean, in the period from 2010 to 2017, is cultivated on an average of 64,542 ha with the least harvested areas being recorded in 2014 (47,104 ha) and the highest in 2017 (85,133 ha). Due to increased sown areas, soybean is positioned as the third most important crop in Croatia, just after maize and wheat and ahead of barley. The increase in soybean harvesting areas can be observed from different points of view. Consumer preferences could represent one of the reasons, and another reason may be the Common Agricultural Policy, which allows the producer a higher production price. Furthermore, relatively safe purchase of soybean seeds and regular sowing times makes a soybeans appealing crop to grow. In the period from 2010 to 2017, average soybean production was 161,073 t, with the least production quantities being recorded in 2011 (96,718 t) and the highest in 2017 (244,075 t). The average yield in the same period was 2.5 t per ha.

Sunflower and rapeseed are, along with soybeans, most important oil crops in Croatia. Favourable weather conditions for the cultivation of sunflower are in eastern parts of Croatia, where it was harvested on the average on 34,695 ha with an average yield of 2.8 t per ha. Official records show significant differences in yield per hectare over a seven-year period which makes sunflower the most variable crop. Cultivation is strongly affected by weather conditions, although due to a well-developed root system, sunflower can give satisfactory yields even in dry years. One of the major disadvantages of sunflower cultivation is that it is susceptible to more diseases that occur more frequently in years with more precipitation.

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Rapeseed is one more crop that shows an increasing trend in arable land. Although grown on an average of 24,032 ha (in the period from 2010 to 2017), in 2016 and 2017 the areas under this crop has doubled, with recent estimates for 2018 suggesting a record harvesting area under this crop of as much as 53,000 ha (Croatian Bureau of Statistics, 2018c). The values refer to rapeseed areas not intended for biodiesel production. Over a seven-year period, with the average production of 66.7 t per year, rapeseed is in sixth place by production, with large discrepancies between years. The most common reason for variations in the size of the sown area is in the sowing period, which is in Croatian conditions from 25th August to 10th September. If drought conditions are present in this period, many farmers are not keen on the cultivation of rapeseed.

The increase in crop production in the overall structure of agricultural production after Croatia's accession to the European Union is due to, among other things, significant changes in the economic environment. Changes in production over the past period are mainly a reflection of market needs for these products and to a lesser extent climate conditions and the prices of oilseeds themselves. The Republic of Croatia is self-sufficient with the production of oilseeds, especially sunflowers, soybeans and rapeseed. In 2015, self-sufficiency in the production of oilseeds was 355.8%. External trade in oilseeds generated a surplus. In 2016, EUR 95.7 million worth of oilseeds were exported, while imports of oilseeds amounted to EUR 12.7 million, resulting in a surplus of EUR 83.1 million.

Oil crop residues are used for feed (protein cake), energy (husks), chemical compound for detergent, soups and cosmetics (technical fatty acid) and biogas substrate.

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2.3.3. Permanent crop production

Permanent crops in Croatia are represented with orchards, olive groves and vineyards. In Croatia, diversified fruit production is possible due to climatic, pedological and hydrological potentials, but this does not mean that it is significantly represented in the total value of crop production output. In the period from 2010 to 2017, fruit production was carried out on average on 30,829 ha accounting for 3,6% of utilized agricultural land with an average production of 193,404 t per year with the least production being recorded in 2017 (121,434 t) and the highest in 2013 (263,441 t). Current fruit production is insufficient in relation to the needs of the population, tourism, the food industry, exports and employment opportunities. In 2016, fruit production accounted for most of the intensive production, which amounted to 151,256 tonnes on an area of 29,289 ha, while extensive production on family farms producing 4,032 tonnes of fruit was significantly smaller.

The most common fruit species produced in the Republic of Croatia during 2016 were mandarins, apples, plums and cherries. In 2015, self-sufficiency in fruit production amounted to only 58.8% of all domestic market needs (self-sufficiency was achieved only for cherry and cherry production with 162%, mandarin with 159.2% and apples with 107.3%). The degree of organization of producers in the fruit sector is low due to fragmented plots and low level of production technology. In addition, Croatia does not have sufficient storage facilities and cold storage and processing capacity and currently has three recognized producer organizations in the fruit and vegetable sector. An indicator of the poor organization of this sector is the fact that in 2016 significantly higher quantities of fruit were imported than were exported from the Republic of Croatia. Fruits import amounted to EUR 172.9 million, while exports amounted to EUR 37.7 million, resulting in a negative foreign trade balance, or a deficit of EUR 135.2 million. Average yields on plantations are lower than those of EU countries due to outdated technology and frequent droughts. There is a need to invest in technical and technological modernization, to introduce new technologies for the production, storage and preparation of products for the market, and to promote the production and organization of the producer market, all with the common aim of ensuring greater productivity growth and job creation.

According to the Croatian Bureau of Statistics, in 2018, an 18,697 ha were under **olive groves**. The total production of olive oil was 28,418 t, and 36,573 hl of olive oil was produced in the same year. The processing of olive oil is gradually increasing, and Croatian olive oil is increasingly becoming an economically important potential in the agricultural production of Mediterranean Croatia, with significantly improved quality. Nevertheless, Croatia's supply of olive oil is insufficient for domestic consumption and considerable quantities are imported. In 2018, according to the Croatian Bureau of Statistics (CBS) data 4,101 tonnes of olive oil was imported, worth EUR 15.3 million, while exports of 289 tonnes of olive oil amounted to EUR 2,6 million in the same period, amounting to a deficit of EUR 12.7 million.

Agro-ecological conditions in the Republic of Croatia are favourable for the cultivation of **vineyards** and the production of grapes from which wines of different quality are produced. The most represented are wines with a protected designation of origin. According to CBS data, there was 20,512 ha of agricultural land under the vineyards in 2018. Grape production in 2018 amounted to 146,242 t. In 2018, the wine production recorded a negative foreign trade balance, i.e. a deficit of EUR 14.3 million.

Wheat, corn and barley, as the three most represented cereal crops, have been traditionally grown in Croatia for years. In the younger generations, these cultures are somewhat resilient, and newer generations are moving to other crops; permanent crops, vegetable crops, etc.

2.3.4. Livestock, related fodder production and use of pastures

In 2016, there was a slight decrease in the share of livestock in the total value of agricultural production, although a small recovery of the livestock stock was recorded at an intensity of 0.5 LU/ha. Currently, 135.026 active farm holdings are registered in the Register of Livestock Farms, with 147,283 owners.

The total number of **cattle** in 2018 was 414,125 and compared to the previous year it decreased by 8.1%, compared to the average of the five-year period from 2013 to 2017, the number of cattle decreased by 7.1%. The share of the Republic of Croatia in the number of European Union bovine animals is 0.5%. In comparison with the previous year 2017, in 2018 in the category of cattle under one year of age there was a slight decrease in the number of cattle by 0.8%. A decrease of 4.3% was observed in the category of slaughter calves, while in the category of other male calves, a decrease of 7.2% was observed and the number of other female calves increased by 8.4%. The number of cows in 2017 decreased by 2.6%, so the rate of decrease in the number of cows is lower than in the previous year.

Despite the decline in the price of **milk** in 2018, overall delivery at EU level did not change significantly. The total quantity of milk delivered to purchasers in the Republic of Croatia amounts to 453,458 t, which is 5.1% less than in 2017. In the period from 2013 to 2018, the number of milk suppliers decreases but the average quantity of milk delivered per supplier increases. In 2018, 6,139 suppliers participated in the delivery of milk to purchasers. Compared to the previous year 2017, the number of suppliers in 2017 decreased by 11.8% and compared to the average number of suppliers in the period from 2013 to 2017 decreased by 36.9%. The average annual delivery of milk per supplier in 2018 is 80,107 kg and compared to the previous year it is higher by 7.3%. Compared to the average amount of milk per supplier in the period from 2013 to 2017 it is increased by 34%.

Structural analysis of suppliers by volume class shows that producers delivering less than 6,000 kg of milk annually accounted for 18.8% of the total number of suppliers, delivering 0.8% of the total milk delivered. The largest quantity of milk delivered comes from 277 suppliers who deliver more than 200,000 kg of milk per year, accounting for only 4.5% of suppliers and delivering as much as 56.8% of the total milk delivered, or an average of 930.06 kg per supplier. At the same time, the data shows that there is a decrease in the number of manufacturers in all quantity categories. In 2018, milk was purchased by 34 dairies and 10 registered small family dairies that process milk produced on their own farm, with the top three milk purchasers buying 77,2% of the total quantities from 74.7% of suppliers. In the Republic of Croatia, the organization of milk producers is present through producer organizations that enable producers to associate and negotiate the price and terms of the purchase of milk through the contract system. By 2017, four producer organizations were active under the "milk package".

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In 2016, live cattle exchanges made a deficit. 130,636 cattle worth EUR 73.1 million were imported while 43,824 cattle worth EUR 45.9 million were exported. Imports of live bovine animals account for the largest share of other cattle from 80 to 160 kg, and in the structure of exports of cattle for slaughter weighing more than 300 kg. When compared to 2017, the value of imports in 2018 increased by 1.3% while the value of exports increased by 75.8%.

In 2017 Croatia imported 18,209 tonnes of fresh or chilled beef and 4,345 tonnes of frozen beef in the total worth EUR 90.8 million, while exported 6,522 tonnes of fresh or chilled beef and 1,057 tonnes of frozen beef in the total worth EUR 32.0 million.

The total number of **pigs** in 2016 was 1,049,123 pigs, which is a decrease of 6.4% compared to 2017. Compared to the average number of pigs in the period 2013-2017, the number of pigs in 2018 decreased by 8.3%. The share of the Republic of Croatia in the number of pigs in the European Union is 0.7%.

The trade in live pigs in 2016 generated a surplus. A total of 485,759 pigs worth EUR 23 million were imported, while 282,065 pigs worth EUR 40.9 million were exported. In the structure of imports of live pigs, the most represented category is domestic pigs (except purebred breeding pigs) weighing up to 50 kg, accounting for 99% of the total number of imported pigs. In comparison with the previous year 2017, the value of imports decreased by 12.2% although 53,301 additional pigs were imported, compared to the previous year, while the value of exports increased by 1.6%.

There was a deficit in the exchange of pork. In 2018, 60,915 tonnes of fresh or chilled pork and 26,614 tonnes of frozen pork with a total value of EUR 179.9 million were imported, while 6,236 tonnes of fresh or chilled pork and 1,205 tonnes of frozen pork with a total value of EUR 20.1 million were exported. In comparison with 2017, the value of pork imports increased by 9%, while the value of exports increased by 6.3%.

The structure of production, as well as the structure of imports and exports, indicates that, due to the lack of sows, insufficient numbers of piglets intended for fattening are produced, which is offset by imports of live animals of younger ages intended for fattening. Also, exports of live fattened pigs and imports of pork and processed products indicate that the slaughterhouse industry does not use domestic raw materials for processing and that primary producers obtain relatively better prices for fattened pigs by export.

Compared to 2015, the total number of **sheep** in 2018 decreased by 0.1% to 636,294 head. The share of the Republic of Croatia in the total number of sheep in the European Union is 0.7%. Of the total number of sheep in the Republic of Croatia, it is estimated that 80% are from original breeds, which are very modest in nutrition and care but also resistant to adverse climatic factors. In the coastal counties, Primorje-Gorski Kotar, Lika-Senj, Zadar, Šibenik-Knin and Split-Dalmatia, there are over 50% of the total recorded sheep, which confirms that sheep breeding is the main livestock branch in these areas.

An analysis of the size of the herd indicates that production on many sheep farms is based as an additional source of income for members of the holding and that only a small number of holdings are sheep being the sole source of income. Generally speaking, in the Republic of Croatia sheep are mostly raised for meat production, especially for the production of light- to medium-weight lamb carcasses, which are desirable for preparation on the spit. Recently, there has been an increased interest in raising sheep for milk production and processing milk on the family farm, especially in cheese. As a result, most of the sheep milk produced is used to feed lambs for slaughter, and only a portion of the remaining milk is used by producers to produce higher value-added sheep milk.

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2.4. Biomass potentials from residues and unused lands

In terms of residual biomass production Croatia scores quite well, compared to other smaller EU countries, as Figure 8 shows. 4.8 million tonnes per year of residues are produced, of which the main sources are cereals and oil crops. Only 1 million tonnes are known to be harvested at this moment (according to the Sankey diagram in Figure 3). How much can be mobilised of these residual resources taking account of sustainability consideration of which the main is the conservation of organic carbon in the soil, will be discussed in next Section 2.3.1 in greater detail.

2.4.1. Lignocellulosic residual biomass potential from crops

As already became clear, Croatia has a relatively large cropping sector and therefore the residual biomass potential from crops are certainly of interest. By-products from arable crop production are mainly in a form of straw, stalk corn and corn cobs. They are used for traditional purposes (bedding) and lately, emerging agropellets for fuel and feed.

How many crop residues (e.g. straw) can be removed sustainably, depends on several factors. The maintenance of soil organic matter is an especially relevant function of straw-removal. Also, the nutrient balance should be maintained, but nutrients are often replenished, by mineral fertilizer application practices. The input of soil organic matter, however, is often only dependent on crop residues left behind. The amount of straw to be kept in the field is complicated to estimate as it depends strongly on the soil and climate characteristics and the long-term management practices. To give a good estimate of residual biomass potentials that can be sustainable removed we will present the results of a national assessment using average of time series data (2012-2016) as input and the methodology by Ćosić et al. (2011) and of the biomass potential assessments in the S2BIOM project (Dees et al., 2017[2]) (See Table 3) .

In Table 3 the primary residue potentials is presented of cereals and grain maize, which produces corn stover, which in the table includes corn husks and leaves and the cobs as assessed by Ćosić et al. (2011) and by S2BIOM. In the methodology from Ćosić et al. (2011) the total available quantities are reduced for soil protection against erosion and related loss of soil organic carbon and animal feed/bedding purposes (see **Box 1**). In S2BIOM the factors involved were the same, but the methodology of calculation was different (see Box 2.2). Furthermore, in S2BIOM a wider assessment was made of more crop residues (Dees et al., 2017) also at regional level (see explanation in **Box 2**) (see also Table 2 3).

Table 3 Availability of primary residual biomass from cereals and grain maize (tonne d.m.) in Croatia

	Cereals straw		Maize stover (excl. cobs)	Maize stover (incl. cobs)	Corn cobs
	S2BIOM *(assuming soil carbon conservation and subtracting straw use for animal bedding & feed)*	Ćosić et al. (2011) using data 2012-2016 *(assuming soil C conservation and use for animals*	S2BIOM *(assuming soil C conservation and NO use for animals*	Ćosić et al. (2011) using data 2012-2016 *(assuming soil C conservation and use for animals)*	Ćosić et al. (2011) using data 2012-2016 *(assuming soil C conservation and use for animals*
Total	**548,496**	**1,000,000**	**1,201,316**	**350,000**	**340,000**

[2] D1.6 A spatial data base on sustainable biomass cost supply of lignocellulosic biomass in Europe - methods & data sources https://www.s2biom.eu/en/publications-reports/s2biom.html

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The amount of cereal straw is quite significant in Croatia amounting to 1 million tonnes d.m., when assessed according to the Ćosić et al., and 550,000 tonnes d.m., when assessed in the S2BIOM approach. The difference is related to the application of a carbon balance model, taking account of diversity in carbon levels in the soils in Croatia, which leads to a larger diversity in sustainable removal rates over the country then the standard fixed sustainable removal rate applied in the Ćosić et al. methodology.

The maize stover availability is also significant but given the large difference between the S2BIOM estimate and the Ćosić et al. approach, one can conclude that a large part of the stover is already going to animal bedding and feed. Still, there is an unused potential of 350,000 tonnes d.m. In addition, a similar amount of biomass should also be available from the remaining cobs. Initiatives are already starting to make pellets from these primary residues.

Box 1 Methodology of Ćosić et al. (2011) explained which was applied to average crop data 2012-2016:

Grain-straw ratio was 1.6 and 0.8 for straw and maize stover, respectively. The average of time series (2012-2016) was applied to reach the total available quantities. Further, restrictions were made for straw removal to prevent wind and water erosion and were set at a fixed level of 1.5 t/ha to be left in the field. The amount to be substracted as competing use needed for livestock use was put at 0.75 t/head cattle. For estimating residues potential from corn, a technical potential of 30% is used and requirements for soil protection from wind and water erosion were estimated at 50% from all biomass of the corn stover.

Box 2 Methodology of S2BIOM to calculate the crop residues potentials in Table 3 and Table 4

It identifies the part of the residues that can be removed from the field without adversely affecting the Soil Or
to demand for straw for animal bedding & feed. For corn stover, rice straw, and sunflower and rape stubb
between the inputs of carbon to the soil and the carbon outputs. A negative balance, i.e. outputs are large
the long term. To calculate the soil carbon balance at regional level S2BIOM used the MITERRA-Europe mode
& Jenkins, 1999) to calculate the soil carbon dynamics in a spatially detailed assessment. For further details or
is given in Annex 2.

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Table 4 Residual biomass potentials[3] from arable crops 2020 in tonne d.m. (=S2BIOM UD1 potential)

County	Cereals straw	Oil seed rape straw	Maize stover	Sugar-beet leaves	Sunflower straw	Total
Primorsko-goranska županija	34,681	2,429	75,958	5,849	4,805	123,722
Ličko-senjska županija	52,156	3,653	114,232	8,797	7,225	186,063
Zadarska županija	35,229	2,467	77,158	5,942	4,880	125,677
Šibensko-kninska županija	28,654	2,007	62,759	4,833	3,970	102,223
Splitsko-dalmatinska županija	43,970	3,080	96,303	7,416	6,091	156,859
Istarska županija	27,255	1,909	59,695	4,597	3,776	97,232
Dubrovačko-neretvanska županija	17,094	1,197	37,440	2,883	2,368	60,983
Grad Zagreb	6,254	438	13,697	1,055	866	22,310
Zagrebačka županija	29,834	2,090	65,343	5,032	4,133	106,432
Krapinsko-zagorska županija	11,974	839	26,226	2,020	1,659	42,717
Varaždinska županija	12,294	861	26,926	2,074	1,703	43,858
Koprivničko-križevačka županija	17,036	1,193	37,312	2,873	2,360	60,775
Međimurska županija	7,073	495	15,492	1,193	980	25,234
Bjelovarsko-bilogorska županija	25,737	1,803	56,370	4,341	3,566	91,817
Virovitičko-podravska županija	19,713	1,381	43,176	3,325	2,731	70,326
Požeško-slavonska županija	17,767	1,244	38,914	2,997	2,461	63,383
Brodsko-posavska županija	19,752	1,383	43,261	3,331	2,736	70,465
Osječko-baranjska županija	39,473	2,765	86,454	6,658	5,468	140,817
Vukovarsko-srijemska županija	23,707	1,660	51,924	3,999	3,284	84,574
Karlovačka županija	35,300	2,472	77,315	5,954	4,890	125,932
Sisačko-moslavačka županija	43,540	3,049	95,361	7,344	6,032	155,325
Total	**548,496**	**38,415**	**1,201,316**	**92,511**	**75,986**	**1,956,724**

[3] Source: S2BIOM project: Dees et al (2017) D1.6 A spatial data base on sustainable biomass cost supply of lignocellulosic biomass in Europe - methods & data sources https://www.s2biom.eu/en/publications-reports/s2biom.html

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When looking at the residual biomass potential per region in Table 4, one can conclude the most important arable crops delivering primary residues are from cereals and maize and sugar beet. Overall, the total quantities of available unused residues are relatively low also have a large spatial distribution. There are, however, clearly a couple of regions which have the largest concentration of sustainable removable arable crop residues which are Ličko-senjska županija, Zadarska županija, Splitsko-dalmatinska županija, Istarska županija, Osječko-baranjska županija and Sisačko-moslavačka županija. It is estimated that, except for a large part of the maize stover, these residues remain unused currently.

2.4.2. Residues from permanent (woody) crops

Current use of by-products from managing permanent crops is at very basic level. Pruning are used either for slow burning as a frost prevention or for heating, although most remain on field or are burned. Pruning potential for energy has been estimated at very wide range, from 0.4 GJ (Elbersen et al., 2016) to 4.21 PJ y-1 (Bilandžija et al., 2012), strongly depending on the methodology This would relate to a range of 0.43 – 263 Ktonnes of permanent crop residues. A more detailed regional explicit potential taking account of sustainable removal rates assessed in Horizon 2020 project *up_running* (2017-2019). When considering pruning potential, 2 PJ y-1 or ~ 100 kt of pruning can be used as a value to start planning (Dyjakon and Garcia-Galindo, 2019).

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2.4.3. Dedicated crop potentials from unused lands

As a part of the EU, Croatia strives to increase the total share of renewables in overall energy production by using and developing technologies for exploiting various renewable energy sources such as the Sun, wind and biomass. Cultivating energy crops has multiple advantages such as: good biomass yield, increasing biodiversity, temporary animal habitat, regeneration of contaminated soil and other ecosystem services. At the same time, Croatia has large areas of agricultural land that are not being cultivated, which is considered as an unused potential. Also, the current economic situation in Croatia is not very good hence every option that could help create jobs and improve the economic situation should be considered.

Research conducted throughout S2BIOM project aimed to assess the potential for energy production from biomass produced from short rotation coppice (SRC) in Croatia. Since there were no energy plantations established at that moment in Croatia, three scenarios were developed to determine technical and energy potential of produced biomass. The energy potential was determined based on the category of ownership for different counties in Croatia. The case study for Croatia was done with 5 selected macro locations. Power plants up to 15 MW of installed capacity were considered. The internal rate of return (IRR) method was chosen to represent the technical and economic analysis of the selected locations for power plants. Projects with IRR higher than 12% were considered profitable. Research showed that only macro location Sisak was profitable with default parameters such as the investment cost, heat energy price, electricity price, etc. For each macro location the sensitivity analysis was done discussing how the change of important factors like the electricity price, transport cost, investment cost and fuel price could change the IRR. Generally, for all macro locations increase of the purchase price of electricity or decrease of the investment cost or fuel price only by 10% would make almost all the projects profitable. Transport cost had a very low influence on the IRR and it was shown that only 50% lower transport cost for some locations could help make projects profitable. The technical and energy potential of biomass calculated based on methodology developed in S2BIOM project are showed in Table 5 and Table 6

Table 5 Technical potential of biomass

	Scenario					
County:	S1 private (tonnes/year)	S1 state (tonnes/year)	S2 private (tonnes/year)	S2 state (tonnes /year)	S3 private (tonnes /year)	S3 state (tonnes /year)
Krapina-Zagorje	6,953.70	449.55	4,635.80	299.70	2,317.90	149.85
Varaždin	5,729.10	3,938.18	3,819.40	2,625.45	1,909.70	1,312.73
Međimurje	11,349.00	6,641.27	7,566.00	4,427.51	3,783.00	1,213.76
Koprivnica-Križevci	3,849.30	9,997.10	2,566.20	6,664.74	1,283.10	3,332.37
Osijek-Baranja	20,732.40	14,924.17	13,821.60	9,949.45	6,910.80	4,974.72
Vukovar-Srijem	10,381.80	17,338.19	6,91.20	11,558.79	3,460.60	5,779.40
Virovitica-Podravina	20,361.90	27,374.72	13,574.60	18,249.82	6,787.30	9,124.91
Zagreb	34,671.00	31,160.77	23,114.00	20,773.84	11,557.00	10,386.92
Bjelovar-Bilogora	60,356.40	38,902.27	40,237.60	25,934.84	20,118.80	12,967.4
Požega-Slavonia	50,212.50	60,026.27	33,475.00	40,017.51	16,737.50	20,008.76
Brod-Posavina	28,571.40	76,790.10	19,047.60	51,193.40	9,523.80	25,596.70
Karlovac	320,810.10	127,794.58	213,873.40	85,196.38	106,936.70	42,598.19
Sisak-Moslavina	223,906.80	131,559.32	149,271.20	87,706.22	74,635.60	43,853.11

Table 6 Overall energy potential

Scenario:	S1 (TJ/year)	S2 (TJ/year)	S3 (TJ/year)
Krapina-Zagorje	90.47	60.31	30.16
Varaždin	118.13	78.76	39.38
Međimurje	219.84	146.56	73.28
Koprivnica-Križevci	169.20	112..80	56.40
Osijek-Baranja	435.72	290.48	145.24
Vukovar-Srijem	338.74	225.83	112.91
Virovitica-Podravina	583.34	388.89	194.45
Zagreb	804.46	536.31	268.15
Bjelovar-Bilogora	1,212.94	808.63	404.31
Požega-Slavonia	1,347.12	898.08	449.04
Brod-Posavina	1,287.52	858.35	429.17
Karlovac	5,481.95	3,654.63	1,827.32
Sisak-Moslavina	4,343.80	2,895.86	1,447.93
Total	24,703.63	2,895.86	1,447.93

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2.4.4. Residual biomass potentials from livestock

The manure potential for biogas in Croatia assessed by the JRC (Scarlat et al. 2018) is based on 4.8 Mt of collectable manure with 5.43 PJ biogas potential or 104 MW. Yet, anaerobic digestion (AD) rarely occurs as mono-digestion and manure represents a co-substrate with lesser energy content. Biogas (and biomethane) potential has been estimated from 5.83 to 11.5 PJ y^{-1} with the prospects to increase by including waste, by-products and residues from food processing streams suitable for AD (Kulišić et al., 2018).

In 2016-2019, within Horizon 2020 project BiogasAction, the future biogas market for Croatia has been outlined. The table below (Table 7**Error! Reference source not found.**) refers to the manure related potential and replication rate as well as the productivity.

Table 7 Biogas potential in Croatia by different beneficiaries (source: Horizon 2020 Biogas Action, 2019)

Size of the plant	<30 kW		<500 kW		1,000 kW
Potential users	**~11,400**		**~2,100**		**40**
Sector	**cattle&pig**	**poultry**	**cattle&pig**	**poultry**	**industry**
Replication potential	**4,900**	**6,500**	**1,250**	**800**	**40**
Biogas	541	715	982	644	135
Electricity	1,028	1,358	2,160	1,416	280
Heat	1,028	1,358	2,160	1,416	280

In 2016-2019, within Horizon 2020 project BiogasAction, the future biogas market for Croatia has been outlined. The Table 7 refers to the manure related potential and replication rate as well as the productivity. Replication rate reflects the number of potential beneficiaries for each category. Depending on the desired outcome of the concerted policy, with the 85% less the investment size and sacrifice of 25% less production of renewable energy, ~5 time more beneficiaries could be addressed in the micro (<30 kW) biogas plants than in small biogas plants category (<500 kW). That decision would not have merit in renewable energy production but in freshwater protection from excess nitrogen leaching and livestock farmers empowerment. On the other hand, true biogas plants with economics of scale (1 MW) have only 40 beneficiaries to be replicated with (Figure 9).

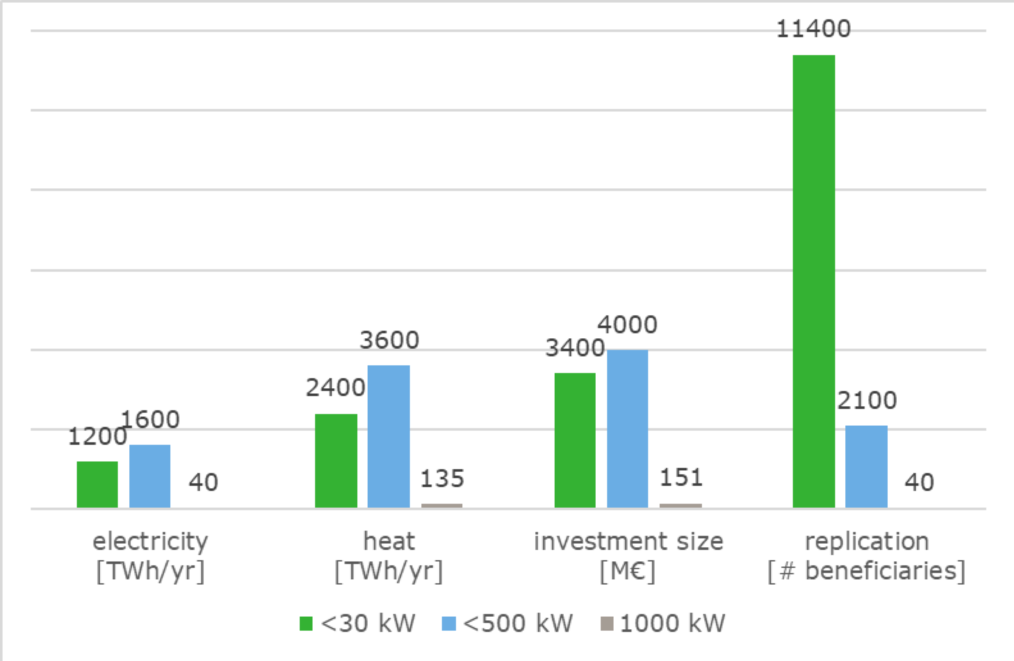

Figure 9 Outlines of the potential future biogas market in Croatia (Kulisic et al., 2018)

At this point, only one biogas plant processes abattoir waste as an AD substrate.

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2.5. Agricultural processing industries

The agri-food sector in the Republic of Croatia has a long tradition and is deeply rooted in rural space, history and development of the country. Due to its preserved nature and environment, Croatia has an advantage over other developed countries and can produce a variety of high-quality food that is safe for consumer health. The food and beverage sector with approximately 55,000 employees accounted for 21% of the manufacturing industry's total employment in January 2019. According to the Labour Force Survey (CBS), which also takes into account informal employment, in the last quarter of 2017, the number of employees in Croatia was 1,639,000. Of these, 116,000 are related to agricultural activities, which is 7% of the total employed. The entire food production chain employs 10% of all employees in Croatia. Important is the existence of all-natural resources that can enable competitive, healthy and safe food production with great potential for raising productivity. Also, as a small and open country, Croatia should not neglect the importance of producing its own food as a long-term strategic security component. Croatian agriculture needs a generally accepted long-term food production strategy that will cover multiple EU programming periods in order to ensure continuity of growth and make the necessary changes in the long run.

Croatia's agri-food sector currently has a very low rate of capital formation (almost 4 times lower), compared to the EU average. Therefore, increasing investment from public and private sources to agricultural knowledge and innovation and facilitating access to productive capital can lead to the necessary stimulus for the growth of labour productivity in Croatian agriculture.

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2.5.1. Main agri-food processing industries

Food and beverage production are an important activity for every country. In the Republic of Croatia, the most profitable activities in this sector are cigarette production and tobacco processing, fish processing, beer production, milk processing, tea and coffee processing, and soft drink production. There are about 10 larger agricultural processing industries in Croatia. The largest ones are in the meat and dairy sectors. These are also the industries that have attracted most foreign investment and operate highly successful companies.

Important are the export products of the food, beverage and tobacco industries: sugar, cigarettes, Vegeta (food supplement), beer, baby food products, salted anchovies etc. Most imported are oilcakes, cigarettes, sugar, mineral water, frozen pork.

The most important export destinations are the agricultural and food products of the markets of neighbouring countries Bosnia and Herzegovina, Italy, Slovenia and Serbia, while the most imported products originate from Germany, Italy, the Netherlands, Brazil and Hungary.

Croatia can offer recognizable products of high quality and originality to the world market. Currently, there are several food products bearing the geographical indication in Croatia: Dalmatian, Drniš and Krk prosciutto, Baranja kulen, Lika potatoes, Zagorje turkey meat and Poljica pie. The designation of origin is: extra virgin olive oil Cres, peeled sauerkraut (cabbage sauerkraut), Varaždin cabbage and Istrian prosciutto.

2.5.2. Main agri-food processing industries

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2.5.3. Side-products from agri-food processing

Residues from fruit processing (pits, pulp, water) represent an excellent opportunity to improve cost efficiency of agri-food processing companies. This is particularly urgent for fruit processing companies. While fruit growing agro-techniques are outdated, food processing industry is able to keep up the pace with the technological development. Generating yield from waste streams just started to be considered as a good opportunity to improve competitiveness. It is likely that hesitation lies in the necessity to step out from the current marketplace and food processing as core business.

In Table 8 an overview is given of secondary residual biomass sources from the wine, olive oil and cereal processing industries (how these potential estimates were assessed is explained in **Box 3**.

Box 3 Methodology of S2BIOM to calculate the secondary residue potentials from food processing

All the secondary agricultural residues presented refer to residues of crops that are mostly grown and processed in the same country. Their assessment can therefore be based on production information (area and/or yield information) derived from national agricultural statistics.

For further details on the whole assessment of biomass potentials in S2BOM consult Dees et al16 and a summary is given in Annex 2.

Wine producers have considered pelletizing grape pomace for either feed or fuel but without significant market uptake. Pomace is usually processed to hard spirit, similar to Italian grappa. There is room to improve competitiveness through increasing the use of by-products in the wine-making process in Croatia.

The use of olive oil residues has been considered in numerous projects but with little success. Recently, a small olive cake pelletizing facility (6,000 t/year) in Istria started producing solid biofuels for the market. The challenge in utilising olive processing waste is their fluctuation over the time: i.e. yield in 2007 (58 hl) and yield in 2014 (11 hl) and high seasonality.

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Table 8 Biomass potentials from agrifood processing industries 2020 in Tonnes d.m. (=S2BIOM base potential) (see also Annex 2)

	Olive stones	Pressed grapes dregs	Cereal bran	Total
Primorsko-goranska županija	257	338	6,979	7,573
Ličko-senjska županija	386	508	10,495	11,389
Zadarska županija	261	343	7,089	7,693
Šibensko-kninska županija	212	279	5,766	6,257
Splitsko-dalmatinska županija	326	428	8,848	9,601
Istarska županija	202	265	5,484	5,952
Dubrovačko-neretvanska županija	127	166	3,440	3,733
Grad Zagreb	46	61	5,343	5,450
Zagrebačka županija	221	290	6,003	6,515
Krapinsko-zagorska županija	89	117	2,409	2,615
Varaždinska županija	91	120	2,474	2,685
Koprivničko-križevačka županija	126	166	3,428	3,720
Međimurska županija	52	69	1,423	1,545
Bjelovarsko-bilogorska županija	191	251	5,179	5,620
Virovitičko-podravska županija	146	192	3,967	4,305
Požeško-slavonska županija	132	173	3,575	3,880
Brodsko-posavska županija	146	192	3,975	4,313
Osječko-baranjska županija	292	384	7,943	8,619
Vukovarsko-srijemska županija	176	231	4,770	5,177
Karlovačka županija	261	344	7,103	7,708
Sisačko-moslavačka županija	322	424	8,761	9,507
Total	**4,062**	**5,340**	**114,454**	**123,856**

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2.6. Cost of main biomass sources

Since for most agricultural residues no commodity market has yet been developed, it is very difficult to provide figures on prices. Instead cost estimates can be presented building on the S2BOM methodology and assessment. The cost refers to Roadside cost and these cover all biomass production collection and pre-treatment cost up to the road where the biomass is located. The roadside cost is a fraction of the total 'at-gate-cost.' For further details on the cost calculation in S2BOM see Annex 2.

Table 9 Roadside cost levels (€/tonne d.m.) for agricultural biomass sources based on S2BIOM cost calculations

Roadside cost for agricultural biomass	Average (€ tonne d.m.)
	(2020 cost level)
Rice straw	24
Cereals straw	19
Oil seed rape straw	16
Maize stover	15
Sugarbeet leaves	40
Sunflower straw	18
Residues from vineyards	197
Residues from fruit tree plantations (apples, pears and soft fruit)	72
Residues from olives tree plantations	106
Residues from citrus tree plantations	77
SRC unused lands	28
Dedicated crops on unused lands	28

2.7. Summary and conclusions in relation to SWOT elements

Biomass production, harvesting and collection in Croatia is a challenge for different reasons. One of these is that biomass is produced dispersed (a low density per area) and is almost by definition bulky, low in energy density and generally contains considerable amounts of water. The idea of bio-hubs as regional facilities to collect, transport and pre-treat biomass in the areas with the highest biomass concentration did not come to life. One exception is Istria, where local farmers are in the process of setting up a hub.

Biomass from the agricultural sector in Croatia has a large potential for future development, but there are also several threats to this development. A SWOT analysis is presented in the following Table 10 to show the Strengths, Weaknesses, Opportunities and Threats of this sector in Croatia.

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Table 10 SWOT analysis for agriculture sector

Strengths	**Weaknesses**
Unused potential available from primary residues, secondary residues and unused lands Roadside cost relatively low and good road connectivity within the country Still many underutilised biomass resources A long agricultural tradition in planned economy Non-utilised arable land Rural Development Program Cost of biomass resources are relatively low in comparison to many regions in the EU	The spatial concentration of biomass is low, makes collection cost relatively high Absolute amounts of agricultural biomass are not very large as the average agricultural land is small, and yields are relatively low The facilities to collect, transport and pre-treat are not in the areas with the highest biomass concentration. Ownership of land unclear and unused lands are very dispersed, so it presents a challenge to mobilise unused land resources Support needed to make investments Market demand for unused biomass not developed Small average size of fields Lack of logistics centres to establish a stable biomass supply
Opportunities Still many biomass resources that can be mobilised Because of harbours (coastal and inland), local biomass resources can be combined with imported resources to strengthen security of supply Unused land resource is significant, so opportunities to produce low-ILUC biomass on abandoned lands Expansion of family farms (both in continental and coastal area) into tourism sector to generate additional income, entrance to new market - ecotourism Production of healthy food for a healthy Europe is a trend the Croatian market can connect to.	**Threats** The risk for loss of HNV farmland when demand for biomass takes off Lack of rural population to produce and collect the biomass in the long term No market for high added value biomass, uses only low-quality chains for heat/electricity Pollution through inefficient use of biomass, pellets in local heat production Favourable work conditions outside of Croatia – increasing trend of labour outflow Raising competitiveness and agricultural development in the EU market could pose a problem for Croatian farmers and their future placement of value-added products Large land purchases for financial investment and industrial agricultural production, without stimulating local communities and creating jobs - Land-grabbing

3. Biomass supply: Forestry

3.1. Introduction

Concerning the National definition of forest, forests cover around 44.0% (total forest land = 2,493 kha, General FMAP 2017) of the Croatian land territory (5,659 kha, Croatian Bureau of Statistics, 2018). Forests in Croatia have predominantly natural structure (95%) and are characterised by diversity and productivity differently distributed within the country, ranging from very productive oak and beech forests in the eastern and central part of the country to degraded macchia and bush-wood forests in the south. From total forest land 79% of area are deciduous forests, 16% coniferous and 5% degraded forests in form of shrubs (Strategy of spatial development (OG 106/2017). Forest cover according to the CORINE land cover is shown in Figure 10.

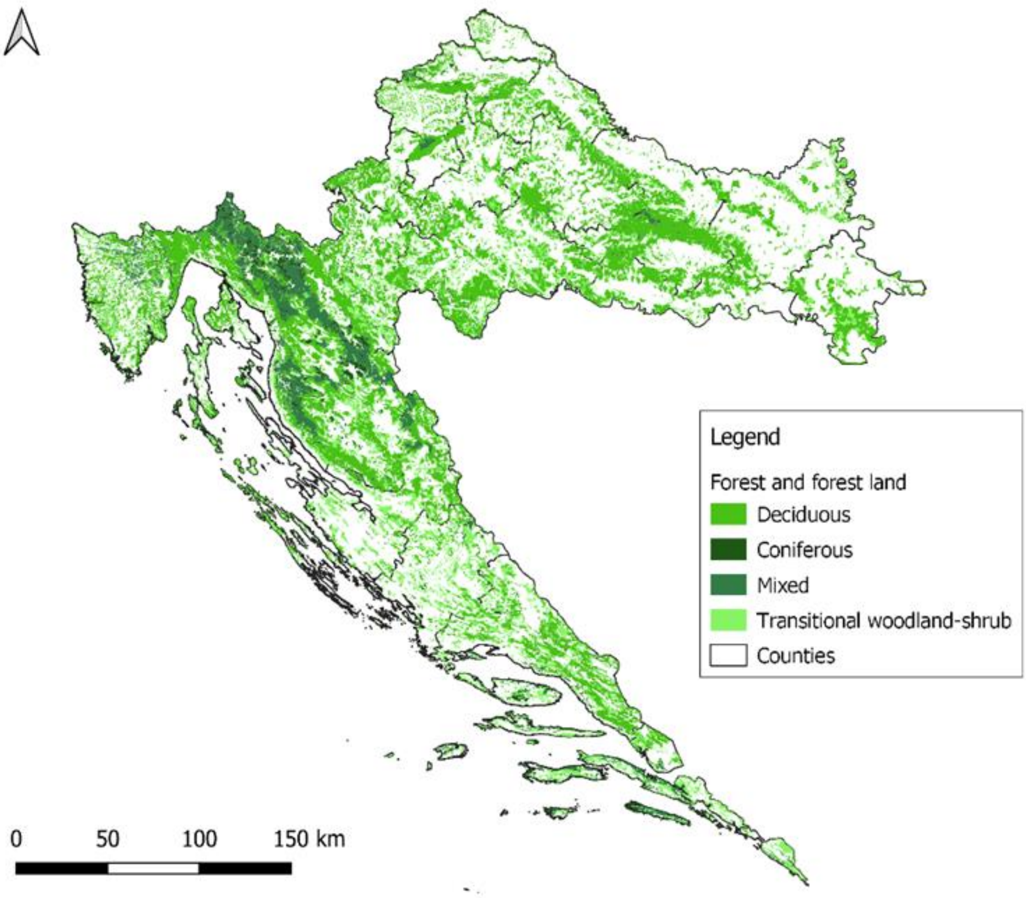

Figure 10 Forest cover in Croatia (source: EIHP based on CORINE 2018)

The distribution of woodland in Croatia (Figure 11) provides an image on source distribution within different Croatian counties[4].

[4] http://www.wisdomprojects.net/global/csdetail.asp?id=15

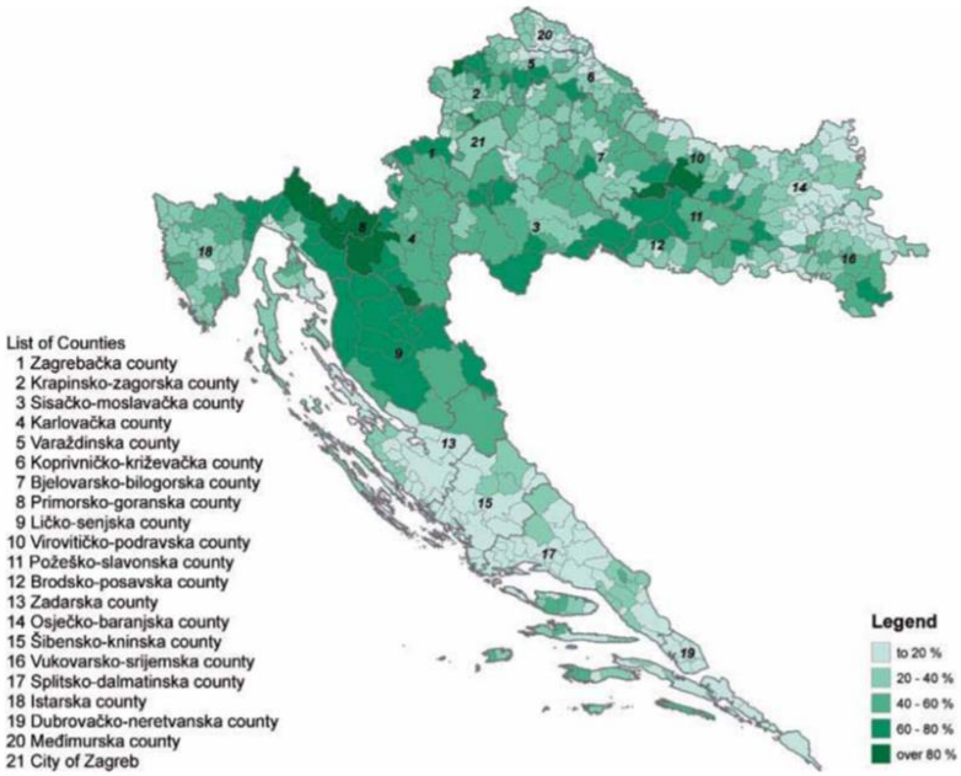

Figure 11 Share of woodland in municipalities/towns (Source: Wisdom)

Total area of forests and forest land in Croatia amounts to 2,759,039 ha. Out of that, 2,097,318 ha (76%) are state-owned, whereas 661,721 ha are privately owned (24%). Vast majority of state-owned Forests (2,018,987 ha) are managed by a state company Hrvatske šume (Croatian Forests Ltd.) (Table 11), and to a lesser extent (<3%) by other Legal bodies owned by the state such as national parks, Faculty of Forestry, Ministry of Defence, "Croatian Waters" etc. The private forests are managed by the private forest owners in accordance with valid forest management plans and with a support of Croatian Forests Ltd. and Ministry of Agriculture.

Except by the ownership, forests are classified according to their purpose as well. The Forest Act states that according to their purpose, forests can be Productive, Protective and a Special purpose forests. The Productive forests are used for the production of forest products, next to the preservation and improvement of their welfare functions, while Protective serve for the protection of soil, waters, settlements etc. Forests with special purpose are within protected nature areas (strict reserves, national parks, nature parks, nature monuments, important landscapes, park forests), forests and parts of forests registered for production of forest seed (seed stands), forests for scientific research, forests for defence of the state.

Accordingly, and based on experts opinion, only the Productive forests have a real potential for woody biomass, while Protective forests (especially those on steep slopes) and Special purpose forests have another primarily function where eventually woody assortments are 'by-products', and the commercial fellings are prohibited in most of those forest categories. Hence, further elaboration regarding potential biomass supply from forests should/ will be based on Productive forests data.

Table 11 Structure of forests & forest land in Croatia by ownership and purpose (Source: General FMAP, 2017)

Ownership	Purpose of forest (land)	Forest (ha)	Land under the forest management			Total (Forest + land under forest management)
			Unstocked productive	Unstocked unproductive	Unfertile	
			ha			
State owned	Productive forests	919,838	36,534	10,643	15,371	982,387
	Protective forests	528,783	99,420	8,343	14,085	650,631
	Forests with special purpose	391,995	55,228	4,685	12,393	464,300
	Sum	**1,840,616**	**191,182**	**23,671**	**41,849**	**2,097,318**
Private	Productive forests	433,973	7,896	1197	357	443,423
	Protective forests	181,355	29	61	20	181,464
	Forests with special purpose	36,733	39	28	34	36,833
	Sum	**652,060**	**7,964**	**1,285**	**411**	**661,720**
State + private	Total	**2,492,676**	**199,146**	**24,955**	**42,260**	**2,759,039**

The structure and area of forests and land under forest management has been changing due to inclusion or exclusion of areas into forest management (according to Act on Agricultural Land (OG 20/2018, 115/2018), article 3; Forest Act (OG 68/2018, 115/2018, 98/2019) article 51 and 52), but in general, total forest area has increased since 2006 for 70.35 kha or 2.6 % (General FMAP, 2017), mostly due to significant increase in private forests area, while state forests area has suffered a slight decrease (around 10 kha).

Forests and forestland in Croatia are governed according to the Forest Act (OG 68/2018, 115/2018, 98/2019 and Ordinance on Forest Management (OG 97/2018, 101/2018), and managed based on the 10-year General Forest Management Area Plan (FMAP), appointing activities that will be performed in the forests and forestland within the complete Croatian forest management area, concerning both state and private forests (General FMAP, 2017). The diversity in the forest management between state forests (with 250 years old forestry tradition and FSC certificate since 2002) managed by company Croatian Forests Ltd. and other state and private forests is at least significant, which can be seen in increasing forest productivity. During the last management period (2006-2015) the management plans have been made for all forest land managed by Croatian forests Ltd., whereas plans were made for only 27% of state forestland managed by other legal bodies and for 66% of forestland managed by private forest owners. However, the latter represents a significant advancement compared to period prior to 2006, when only 6% of private forests had

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management plans. The main factors inhibiting greater management of private forests are small size of forest parcels (average size around 0.43ha) and fragmented ownership of same forests by several owners (Strategy of spatial development (OG 106/2017).

Within the forest growing stock, the dominant origin of forests[5] are seed forests present at 56% of forest area. However, significant shares of forests area constitute of degraded forms such as shrubs (18%) and coppice (14%) (Figure 12).

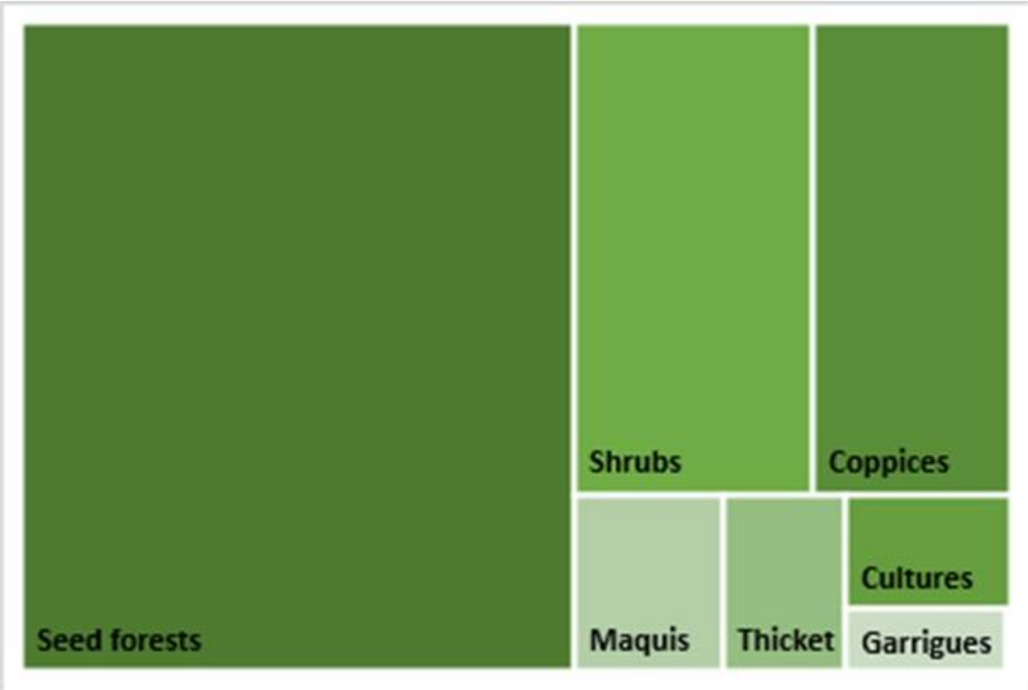

Figure 12 Forest growing stock origin in forested areas (ha) (Source: General FMAP, 2017)

According to the data shown in Figure 13 it is evident that Productive forests regardless ownership, take only 54% of total forestland, but contain 72% of the forest growing stock, which indicates their high productivity. Protective forests occupy 28.5% of forestland but contribute with only 6% to forest growing stock with only 108 m^3/ha.

[5] Seed forests – stands formed by trees originated from seed or seedling; coppices – stands formed by threes originated from stump or roots; cultures- artificial stands developed without application of agrotechnical measures; degraded stands (shrubs, maquis, thicket, garrigue) - degraded stands formed by different trees forms and shrubs (Regulation on forest management (OG 97/18, 101/18)

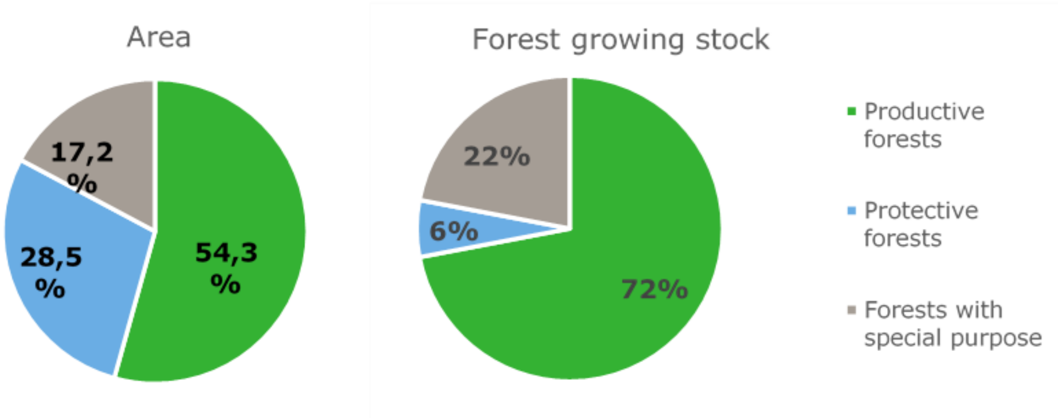

Figure 13 Comparison of forestland area and forest growing stock in different forest categories by purpose

The main characteristics of the forestry sector compared to EU forestry sector are shown in Table 12.

Table 12 Overview of main characteristics of forestry sector in Croatia

Category	Croatia*	EU average	Unit
Forest area	0.67	0.650	ha/capita
Forest increment**	5.87	5.47	m^3/ha
	1.74	2.80	m^3/capita (2010)

** based on population and forest area for 2018*

*** excludes trees in first age class*

Regarding Productive forests, the General FMAP 2016-2025 determines total growing stock of about 303 mil. m^3 in 2016 (for comparison 418 mil. m^3 for forests of all categories) calculated based on the measured diameters at breast height and height of living trees above the taxation level (10 cm in breast height diameter). The average annual increment in 2016 for all forests in Croatia is 5.87 m^3/ha. There is significant difference in average annual increment between private and state forests. Annual increment in state-owned Productive forest is 7.01 m^3/ha, whereas annual increment in privately-owned Productive forests is 4.94 m^3/ha in 2016. Lower increment in private forests is a historical result of a lack of adequate management in (not all) private forests. Comparing 2006, in 2016 the total growing stock of all forests increased for 5% (20.6 million m^3), while annual increment decreased for 4%, mostly resulting from decrease of periodic increment in state forests (465,000 m^3).

Out of total growing stock 80% is under state-owned forest (75% by Croatian Forests Ltd. and 5% forests owned by other legal bodies) and ten most common tree species: common beech (37% of total growing stock), pedunculate oak (12%), sessile oak (9%), common hornbeam (8%), European silver fir (8%), narrow-leafed ash (3%), spruce (2%), black locust (2%), black alder (2%) and turkey oak (2%). The average growing stock in Productive forests is 258 m^3/ha. However, the growing stock in state Productive forests is determined to 293 m^3/ha while the stock within private Productive forests is determined to 186 m^3/ha (General FMAP, 2017). The growing stock is not measured for the first age class of even-aged forest, and in case of maquies and shrub forests estimation was performed using the expert judgement on increment in these forests.

The growing stock can be disturbed by natural calamities and human caused disasters, which have occurred lately in Croatia. Forest fires predominantly appear in southern parts of the country and do not affect the most productive forests. However, forest fires do affect Protective forests and forests with special purpose and their ecological services. With exception of 2017, when total forestland area affected by fires was 41,174 ha, the yearly affected area by fires within the last 10 years was below 10,000 ha (Figure 14).

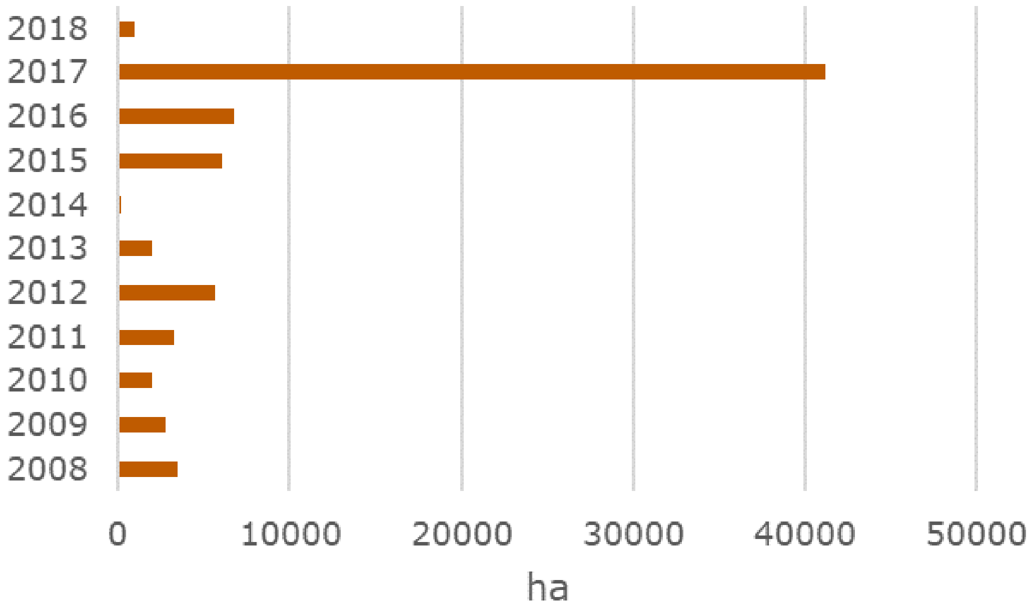

Figure 14 Area of forestland affected by forest fires (Croatian bureau of Statistics, 2018a)

On the other hand, high productive forests are often affected by storms and infestations which results in higher annual cut than expected in affected areas. In 2018, from total gross cut of wood made in state owned forests managed by Croatian forests 1.6 million m^3 come from dry wood, damaged wood by wind, snow, ice and illegal cutting (Croatian Forests, 2019).

Around 34,000 ha of forestland (~1%) is under mined areas which means that is temporary out of the management and silvicultural works. The removal of mines is expected in the future.

3.2. Primary biomass resources from forestry, current and planned harvest levels and uses

Croatia has a relatively large forest potential for the small size country it is. This results in a large primary and secondary forestry potential. Forests are considered as one of the most important resources for Croatian economy, both as energy source and feedstock for wood processing industry (Table 14). In the previous General FMAP period (2006-2015) the overall forest cut (felling) was achieved at 60% of total area proscribed for cut and accounted for 86% of proscribed cut volume in all forests. The difference between the planned and achieved cut is shown in Table 13, as well as prescribed harvest for current General FMAP encompassing the period from 2016-2025.

Table 13 Planned and achieved cut in period 2006-2015 and prescribed harvest for period 2016-2025 (General FMAP, 2017)

FMAP 2006 - 2015	Prescribed harvest	Achieved cut	% achieved	Prescribed harvest in 2016-2025 (m^3)	Prescribed harvest in 2016-2025 (tonnes d.m.)
	m^3				
Croatian forests Ltd.	57,935,018	53,639,369	93	64,196,393	36,881,791
Other legal bodies	661,366	128,463	19	525,372	301,834
Private forest owners*	7,047,369	2,392,543	34	15,649,957	8,991,135
Total period	65,643,753	56,160,375	86	80,371,722	46,174,760
Total annually	6,564,375	5,616,038	/	8,037,172	4,617,476

*The numbers regarding private owners includes wood assortments derived from management units for which management plans have not been made at the time. This number should be taken with caution due to reliability and availability of data for this estimation since for some years data were not available.

According to the Forest Management Area plan for period 2016-2025 the Prescribed harvest (felling) in this period is 80,371,722 m^3 on total area of 1,288,821 ha (Table 13). Regarding previous management period 2006-2015, this represents a total increase in cut for 14,727,969 m^3, followed by a decrease in total area available for cut for 12,988 ha, which implies higher cut on smaller area. This is primarily a result of increased cut both in state and private forests, and a decrease in area for cut in state forests (61,560 ha) and increase of area for cut in private forests (48,579 ha).

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The structure of forest assortments production in 2018 is shown in Table 14. From the total cut in 2018, 2.18 mil. m^3 was fuel wood and 3.21 mil. m^3 industrial wood. From the Table 13 it is evident that the total cut (felling) in 2016-2018 was lower than the average cut in the previous management period and a prescribed harvest for current period.

Table 14 The structure of forest wood assortments production in period 2016- 2018 (Croatian bureau of Statistics, 2018a)

Forest assortment production	2016	2017	2018
		m^3	
Fuel wood (including charcoal)	1,768,000	1,858,000	2,176,000
Industrial roundwood			
Sawlogs and veneer logs	2,402,000	2,392,000	2,675,000
Pulpwood	988,000	1,052,000	533,000
Other industrial roundwood	7,000	5,000	6,000
TOTAL wood (m^3)	5,165,000	5,307,000	5,390,000
TOTAL wood (Tonne d.m.)	2,967,370	3,048,951	3,096,636

Croatian Forests Ltd. are by far the largest primary biomass producer and the largest woodchip producer at the domestic market (capacity of around 850,000 mil. m^3). The contracts for woodchip supply were assigned through contracts in 2015 for 640,000 tonnes and additional 120,000 tonnes in 2016. The existing contracts were revised in 2019, and biomass was allocated from cogenerations that have not fulfilled the requirements to the new subjects selected through the public tender. The interest in biomass was much higher than quantities available (265,000 t of woodchips or 265,000 m^3 of fuel wood) and allocated through the public tender, which indicated a need for more biomass among energy producers. Currently there are 33 woody biomass power plants in operation with total installed capacity of 70.714 MW. Additional 18 plants with 39.394 MW installed capacity have contracts for power purchase but are still not operational (HROTE, data from August 2019). The quota for biomass cogeneration is set on 120 MW, but the interest is much higher indicated by exceeded application for additional 51 MW. Along Croatian Forests Ltd. as main biomass producer, there are several additional smaller producers of woodchips.

The prescribed harvest in state-owned forests in 2018 within the different management unit is shown in Figure 15. On geographical scale, the largest fellings/cuttings can be expected in areas with the largest primary biomass production, and these are areas in continental and mountainous parts of Croatia. There, the residues can be easier collected due to already available machinery and established logistic chains. The felling in coastal regions (Forest administration (FA) Split and Buzet) is very small compared to continental FAs. The reason for the low felling rate is that coastal forests do not have large economic values, predominantly due to their structure (high share of degraded forms), but also technical limitation such as relief.

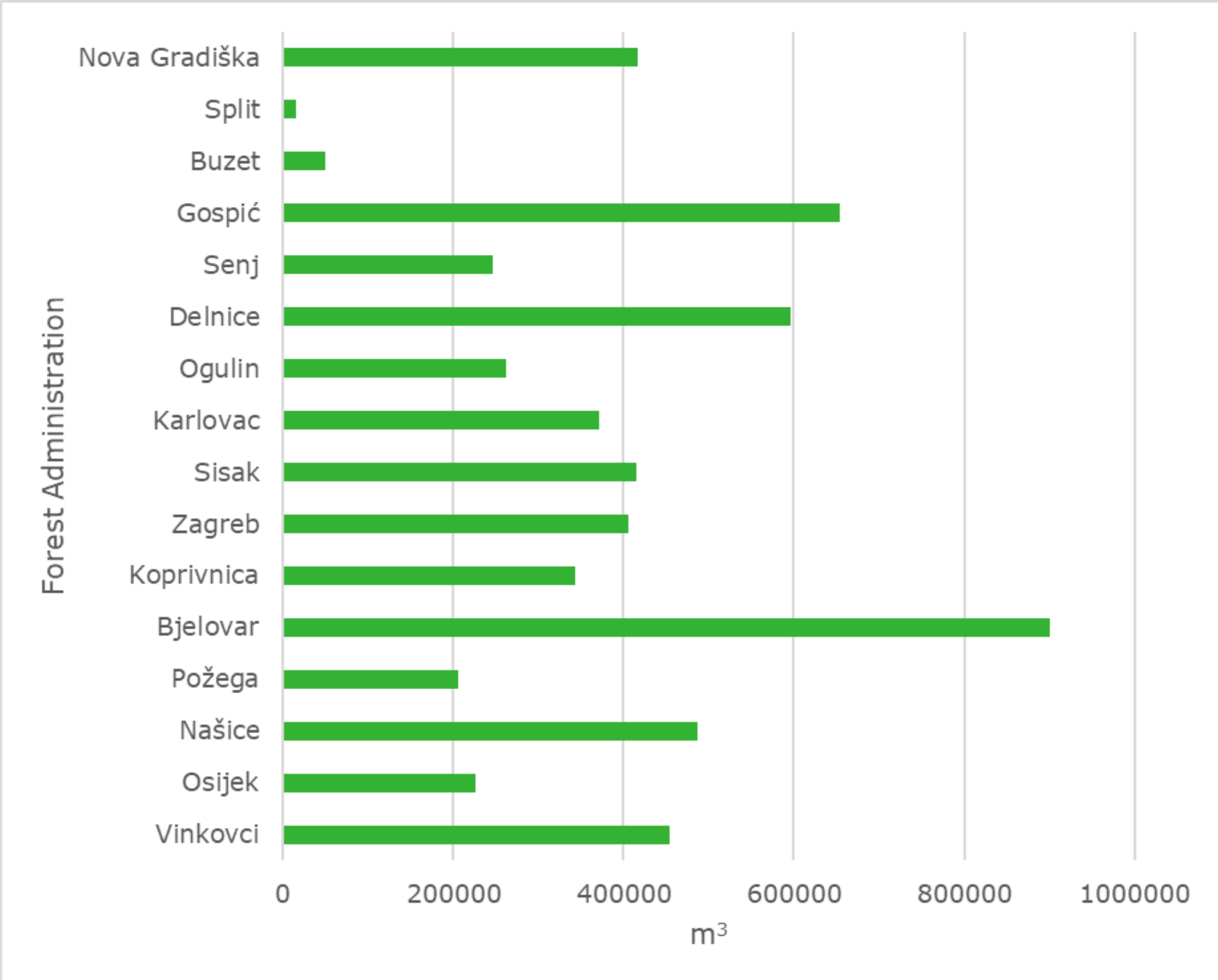

Figure 15 Prescribed harvest (felling) in 2018 in state-owned forests managed by Croatian Forests Ltd. (75% of total growing stock of all forests)

The data on fuel wood production from Croatian Bureau of Statistics shown in Table 14, are significantly different from data provided in Energy in Croatia 2018 (EIHP, 2019), which indicated production of 5.98 mil. m^3 of fuel wood, an amount that is double from the one reported by statistics. This indicates a general problem of reliability of solid information, what can significantly impact estimation of available potentials. Regardless the amounts, biomass as a fuel is especially important for households that make 87% of energy consumption from biomass, with only 1% of modern biomass share (pellets, briquets) (EIHP, 2019).

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In Table 13 an overview was given of the total harvested volume of forest biomass and the prescribed cuts over 2016-2025. From Table 14 it is evident that the average yearly harvest of primary forest biomass was at 5.3 mil. m^3 which is around 3 mil. tonnes of dry mass. The prescribed harvest in 2016-2025 foresees a clear increase in this harvest which amounts to 46 mil. tonnes d.m. in 10 years which equals a yearly harvest of 4.6 million tonnes d.m. When this is to be compared with prescribed harvest to what is estimated to be available as harvestable potentials in the S2BIOM biomass assessments for forests, one can conclude that the current average yearly harvest as reported by the Croatian Bureau of Statistics (Table 14) is in line with the 2020 potential of 3.3 mil. tonnes d.m. in S2BIOM. This means that the exploitation of forest biomass from forests in Croatia is relatively in line with what can also be potentially harvested from the forest.

The prescribed harvest figures in Table 13 of 46 mil. tonnes of forest biomass in 10 years (2016-2025) show that a further mobilisation of biomass in Croatia's forests is clearly intended. For the mobilisation of this forest biomass the growth in forest harvest should particularly come from the private forest owners. The EFI-GTM harvest levels expressed as proportion of the increment in Table 15 confirm that there is certainly room in Croatia for mobilising additional forest biomass.

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Table 15 2010, 2020 and 2030 EFI-GTM harvest levels expressed as % of yearly average biomass increment level in forests. (Elbersen et al., 2016; Biomass Policies project)

		% Harvest & residues potential/Increment		
	Country	***2010***	***2020***	***2030***
AT	Austria	60%	53%	59%
BE	Belgium	55%	55%	53%
BG	Bulgaria	22%	18%	18%
HR	**Croatia**	**72%**	**67%**	**64%**
CZ	Czech republic	69%	75%	72%
DK	Denmark	24%	17%	17%
EE	Estonia	56%	68%	68%
FI	Finland	59%	57%	53%
FR	France	29%	26%	35%
DE	Germany	43%	47%	50%
EL	Greece	35%	46%	48%
HU	Hungary	23%	33%	30%
IE	Ireland	36%	40%	47%
IT	Italy	8%	10%	13%
LV	Latvia	44%	42%	55%
LT	Lithuania	49%	49%	53%
LU	Luxembourg	44%	48%	63%
NL	Netherlands	36%	31%	33%
PL	Poland	47%	56%	53%
PT	Portugal	58%	56%	63%
RO	Romania	26%	36%	35%
SK	Slovakia	95%	81%	82%
SI	Slovenia	21%	31%	45%
ES	Spain	41%	39%	35%
SE	Sweden	69%	62%	62%
UK	United Kingdom	45%	47%	49%

According to the General FMAP 2016-2025, in the previous forest management period (2006 -2014, + planned in 2015) 92% of the prescribed harvest in state owned forests was achieved, while only 34% in private forests. This indicates that a certain potential in the private forests remained unutilised. The underlying reason for such underperformance in private forests is that forests are often inherited by people who do not rely on forestry as income nor manage their forests actively. However, there is also a harvest in private forests which is not registered in the system. Due to unregistered harvest it can be assumed that the percentage of achieved harvest in private forests is higher, but it is not possible to provide an exact number.

The prescribed harvest for 2016-2025 period increased for 14.74 mil. m^3 compared to prescribed harvest in previous management period and it is around 24 mil. m^3 higher than achieved harvest in previous period. This signals the

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potential availability of additional biomass according to the prescribed harvest for current period. The increase in the harvest is expected to come from both private and state forests (Table 13).

The biomass availability for production of energy was estimated for the *Energy Development Strategy for the Republic of Croatia for 2030 with a view to 2050* and the numbers are shown in Table 16. The estimation is based on current General FMAP, available other documents and expert estimations. The table provides total available biomass from primary forestry for energy or other purposes without consideration of current use and potential for biomass mobilisation. The availability for all categories but Forest residues is copied from the FMAP for both private and state-owned forests.

Table 16 Availability of biomass for energy from primary forestry (EIHP, 2019)

Available biomass for energy*	Amount (m^3)	Amount (tonnes)
Industrial roundwood	887,216	509,719
Fuel wood	2,653,845	1,524,674
Wood residues	1,135,792	652,530
Forest residues <7 cm in diameter with bark, measured on thicker end	224,237	128,828
Total	4,901,090	2,815,750

*Current use is not excluded from numbers. Dead wood and other biomass from maintenance are not included.

Strategy for wood processing and furniture production development (2017) indicates that some other sources estimate availability of 0.75 mil. m^3 of forest coproducts and 2 mil. m^3 of fuelwood annually for energy and industrial production. The Strategy also indicates the total stock of around 33 mil. m^3 of dead wood in forests. However, the dead wood is important for biodiversity conservation and certain amounts should be left in the forest.

Currently, most of the produced primary biomass has been allocated to various established pathways. The additional biomass from current production can arise either from greater efficiency in current pathways (transition to higher efficiency technologies that would minimise the need for fuel wood among households) or by mobilisation of unused or additional biomass (termination of contracts for feedstock supply due to non-compliance with the contractual commitments and redirection to other customers, utilisation of harvesting residues -wood under 7 cm in diameter, utilisation of wood from maintenance of forest infrastructure. Additional harvest, and therefore quantities of biomass, are expected from both state and private forests through increased annual prescribed harvest defined within the valid General Forest Management Area Plan. The available potential from the increased cut will greatly depend on the primary biomass needs for the wood processing industry.

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3.3. Secondary biomass resources from forestry: wood processing industries

Secondary forestry residues from sawmills and wood processing industries build on the potentials assessed in EUWood and S2BIOM in combination with some up-dated data from national sources.

Wood processing and furniture production is an important segment of Croatian economy. It represents 6.14% of industrial production, contribution 3.6% to the GDP. There are ~40 sawmills with maximal capacity of stemwood processing 1.1 mil. m^3/annually (Ministry of Environment and Energy, 2019).

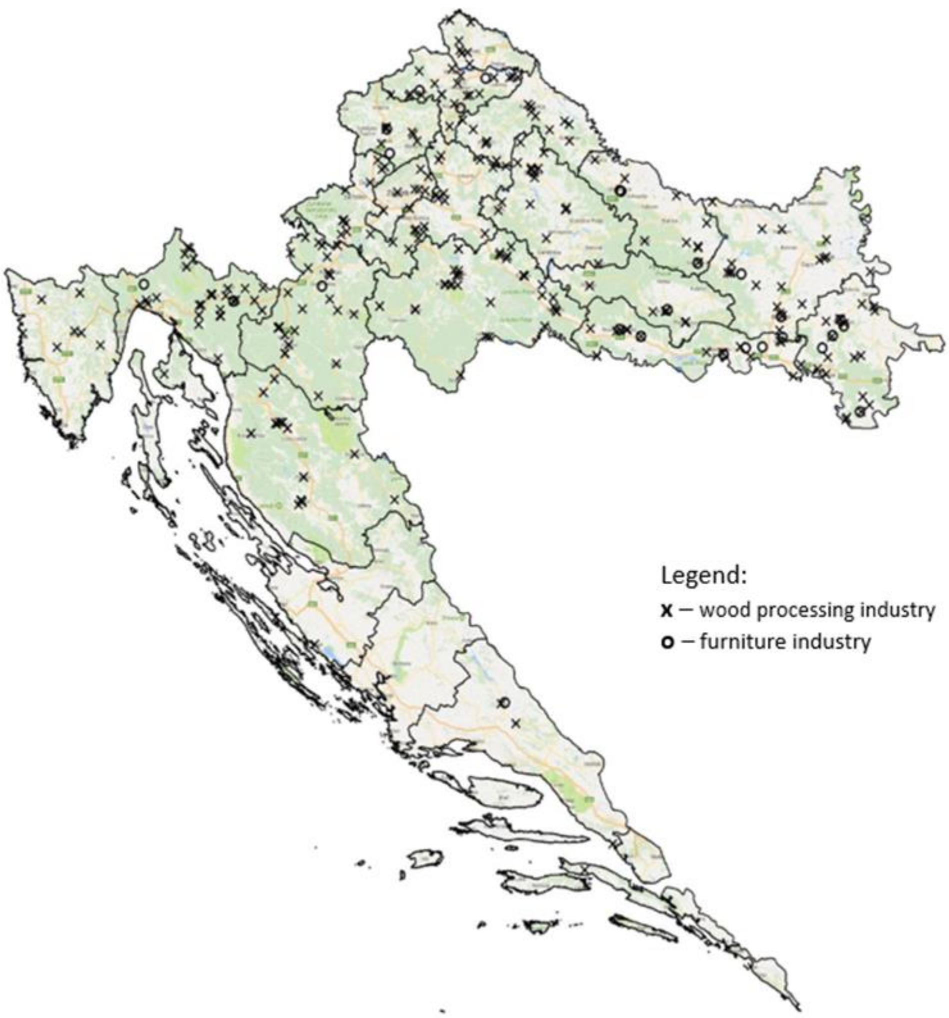

Figure 16 Distribution of wood processing subjects and furniture industry (Source: Strategy for wood processing and furniture production development, with action plan 2017-2020)

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Most important wood products include furniture (tables, chairs, beds, …), furniture elements, flooring, dredged boards etc. There are more than 3,500 companies related to wood industry. It is evident that Croatia has well developed wood processing and furniture industry, mostly located in areas with better access to wood supply such as continental Croatia. The structure of industrial products from forestry achieved in year 2018 is shown in Table 17.

Table 17 Structure of industrial products from forestry (Croatian Bureau of Statistics, 2018a)

Industrial product	Amount
Charcoal	10,000 (t)
Wood chips, particles and residues	587,400 (m^3)
Wood pellets	305,900 (t)
Other agglomerats	56,200 (t)
Sawnwood	1,459,700 (m^3)
Wood based panels	183,000 (m^3)
Pulp wood	38,800 (t)
Paper and paperboard	333,200 (t)

The amount of residues that result out of the wood processing industry is estimated by EIHP for development of *Energy Development Strategy for the Republic of Croatia for 2030 with a view to 2050* and indicated in Table 18.

Table 18 Availability of secondary biomass from forestry (Ministry of Environment and Energy, 2019)

Secondary biomass	Amount
Residues from wood processing industry	1,291,854 m^3
Sawnmill residues with bark	293,261 m^3
Other sources*	300,000 t

* Wood waste from construction sites, wood residues from landscaping etc.

From the table it is seen that larger amounts of residues from wood industry are potentially available for biobased industries. However, many wood processing industries nowadays have adjacent cogeneration plants in which they utilise residues from their processes (e.g. sawdust). This has proved to be most convenient way to manage waste wood and to secure cheaper heat and power for industrial processes. The exact quantity of waste wood is unknown due to incomplete reporting to the Ministry of Environment and Energy by all wood processing companies. In 2017 some 97,906 t of non-hazardous wood waste from furniture industry, wood processing, paper and cellulose production (Category 03) was registered in the Registry of environment polluters. The structure and quantities of the waste in the Registry, related to wood only, is shown in Table 19.

Table 19 Reported amounts of wood industry processing residues in 2017

Code	Type	Amount reported (t)
03 01 01	Bark and pluto residues from furniture production	9,294
03 01 05	Sawdust, slabs, shavings, peeler cores, offcuts	63,466
03 01 99	Other	20
03 03 01	Bark and other residues from cellulose and paper production	42

The above listed categories make 72,822 t of waste wood. From these reported amounts, the use as a fuel and energy production is reported for 34,208 t, while other amounts are either composted, disposed or mixed with other materials.

Due to the size of the wood processing industry significant amounts of secondary biomass can be expected. The general conclusion is that available data are uncomplete and inconsistent to make an adequate estimation of potential from wood processing industry, mostly because current level at which residues are used is unknown.

In the future, the expected increase in the annual cut should also create larger quantities of wood intended for processing and consequentially larger amounts of secondary residues from wood processing industry.

3.4. Forest biomass mobilisation options

Primary forest potential estimated through S2Biom project is around 61 PJ, while potential calculated by EIHP's experts' range between 35.5 – 68.42 PJ/annually or even 100 PJ if mobilisation measures are applied. The potential is based on Forest management plans and various estimations of potential from wood processing industry. However, certain amounts of potential are not registered in the statistic system. This refers primarily to the uncertainty of fuel wood extracted from forests, and residues from wood industry. A detailed survey among industry is needed to establish quantities of wood residues produced and their pathways.

The amounts and pathways of biomass from maintenance of transmission lines, paths for fire protection, maintenance of roads and other infrastructure are not recorded within these numbers. This potentially represents a significant source of biomass that should be further explored.

Out of the total amount of industrial wood and fuelwood harvested almost 50% was allocated for households while remaining 50% was allocated for other energy purposes (cogeneration of electricity and heat, pellet, briquette and charcoal production), industry (paper, plywood, furniture…) and export. Since the amount of industrial roundwood and fuelwood is limited, there is obviously a competition for the same feedstock between energy and industry (wood processing), and within the energy sector itself (solid biofuels, electricity production). The data on fuel wood produced is significantly different between sources.

Croatian Forests Ltd. is and will remain the main biomass supplier for the market, due to established procedures and quantity of biomass. Based on the FMP they establish the amounts and set the price for biomass that can be supplied. However, wood from forestry in state forests has its own pathways already established, most of it is already contracted. New bioenergy developments will have to rely more on biomass from private forests and wood processing industry, or amount coming from increased annual cut.

In regard to the private forests, there are some major problems for the utilisation of growing stock from private forest, such as fragmentation and small parcel size with often several owners. The owners are often elderly people, or they live far from the property and are not aware of the existing biomass market for energy production. Inconsistent forest management in most of private forests has resulted in growing stock per hectare more than two-times lower than in the state-owned forests. To achieve better management, education and information of private forest owners is needed. Although mobilisation of this resource is planned, it is not possible to predict to which extent and when it would happen. Some estimates indicate potential of 200,000 tonnes annually.

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The General FMAP 2016-2025 predicts an increase in the allowed annual felling rate, compared to the previous management period. The harvesting is still significantly below annual increment. Part of this "newly" available biomass can be directed in biobased industries or energy production.

Wood industry is also a significant source of wood residues that can be used for energy production or other purposes. The availability will depend on production of main products and the pathways the wood residues take (e.g. feedstock for other material products). Wood residues from wood processing industry are for the most part already being used by the industry for own energy production needs or sold on the market.

Forest harvesting residues can also be collected. However, further assessments are needed to establish their location and the available amounts which can be recovered at acceptable costs and without harmful environmental effects.

3.5. Summary and conclusions in relation to SWOT elements

In Croatia, forestry and wood processing sectors have a long tradition and are well developed. There are 336 companies licenced for forest works and fellings with different allowed annual quantities, but in the total amount of 5.04 mil. m^3 annually, excluding Croatian forests. This indicates the existence of knowledge, machinery, people. Most state forests are managed sustainably (FSC) and over 150 wood processing firms have 150 FSC COC. The use of traditional biomass (fire logs) in inefficient stoves is extensive. Transition to modern biomass such as pellets would mean greater efficiency in feedstock transformation. Additional harvest of 2.4 mil m^3 annually in comparison to achieved cut in the previous period is allowed. The fact that the planned cut has not been realised in the last management period and has been increased in current management period leaves space for biomass use. Statistical data are sometimes weak or contradictory. This is especially valid in the case of fuelwood and wood residues from wood processing industry. Private forests were not so far an important source of biomass, but this is expected to change in future, especially with support from EU funds for rural development. The competition for industrial roundwood between different sectors and within sectors is significant. Therefore, the attention should be directed towards projects with the best efficiency. Forest biomass potential is significant and further additional mobilisation plans are already well on their way. The State forest sector manages a large forest area, which makes it easier to contract and collect efficiently.

In future, it is necessary to improve infrastructure to mobilise biomass in areas that are more remote and establish a group of private forest owners to manage their land more successfully. Furthermore, restrictions on the type of biomass that can be utilised to avoid competition with other uses to allow currently established flows to operate should be set. A SWOT analysis is presented in the following Table 20 to show the Strengths, Weaknesses, Opportunities and Threats of this sector in Croatia.

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Table 20 SWOT analysis for forestry sector

Strengths	**Weaknesses**
A long sectoral tradition in forestry and wood processing industry Sustainable management of most forests - FSC 150 wood processing companies have FSC COCs Skilled and qualified workforce as result of long tradition Large state-owned forest Knowledge of cascading use of wood Significant additional mobilisation of primary forest resources possible and also already planned Forest processing industry is growing and leads to more secondary forestry residues	Short and vertical value chain Lack of national statistics on biomass flow balance (information to improve planning of forest biomass exploitation) Lack of industry for glued boards and chipboard, pulp, paper… Inconsistent potential statistics High percentage of firewood in energy balance Lack of bio-hubs for storage, pre-treatment and processing Poor management of private forests
Opportunities	**Threats**
Mobilisation of unused biomass Development of new bio-based products on lignocellulosic base Private forest owners Biomass production for low ILUC biofuels	Climate changes in terms of - increasing numbers of forest fires - drought - prolonged vegetation season - mild winters suitable for diseases and pests - infestations with insects and diseases atypical for this geographical and climatic area etc. Energy poverty Unsustainable management of private forests

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4. Biomass supply: Waste

4.1. Introduction

In Croatia, waste management is currently one of the largest challenges in the environmental sector and certainly one of the most demanding areas in terms of adjustment to the standards of the European Union. Solving these issues and orientation toward integral and modern waste management are one the requirements a sustainable waste management system and implementation of Circular Economy and Bioeconomy principles. The issues that the country needs to address are following: stop the increase in solid waste, improvement of recycling programs, improvement of data availability concerning flows and quantities of waste (segments) and improvement of organization of disposal sites and management of waste particularly waste separation.

Currently, municipal waste management in Croatia is undergoing a radical transformation from decentralized disposal of non-treated waste on numerous local sub-standard landfills within counties to centralized waste management and Waste Management Centres (WMC) serving the needs of one county or, in some cases, of several counties. The WMC concept has been adopted by the Croatian Government in its National Waste Management Plan (Government of Republic of Croatia, 2017).

Croatian strategic documents related to waste management are *Waste Management Plan for Republic of Croatia for period 2017-2022* (OG 3/2017) and *Waste Management Strategy for Republic of Croatia* (OG 178/04 – a part of Environment protection strategy), which are aligned with European legislation and strategies. The purpose of these documents is creation of a framework within which Croatia can reduce its waste amounts and manage these amounts in a sustainable manner, within principles of Circular Economy and Bioeconomy.

Within mentioned documents, significant number of regulations, ordinances and statutes are mentioned, that define the following:

- Basic goals and measures for waste management;
- Measures for hazardous waste management;
- Guidelines for waste recovery and treatment.

Moreover, Croatian Waste Management Strategy prescribes the maximum allowed mass of biodegradable waste that can annually be landfilled in Croatia, compared to mass of biodegradable municipal waste produced in 1997 and it is following:

- 75%, i.e. 567,131 tonnes by 31st December 2013
- 50%, i.e. 378,088 tonnes by 31st December 2016
- 35%, i.e. 264,661 tonnes by 31st December 2020.

Figure 17 shows the current status and progress of Croatia in terms of biodegradable waste management, and it can be seen that there is still much room for improvement in this sector.

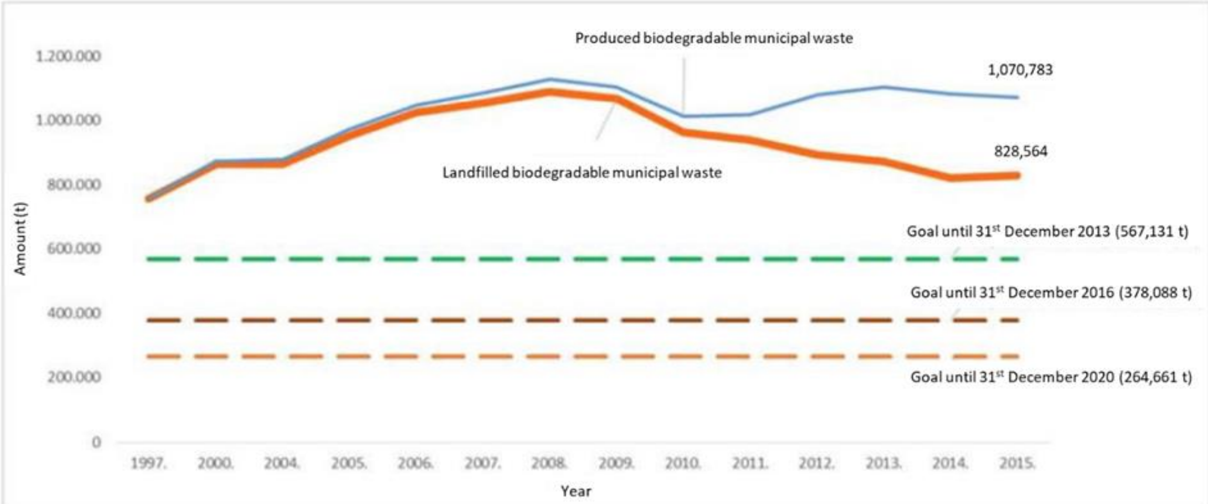

Figure 17 Produced and landfilled biodegradable municipal waste in period from 1997 to 2015, in relation to prescribed goals (Government of Republic of Croatia, 2017)

In order to reduce the amounts of biodegradable waste that is landfilled, separate collection of biodegradable municipal waste is legally defined, with goal of its material and/or energy recovery through composting, digestion (aerobic, anaerobic)[6].

Moreover, in order to implement the Circular Economy and Bioeconomy strategies, Croatia needs to define waste streams that are available for energy and material recovery, which could be returned to the production cycle.

[6] Law on sustainable waste management for Republic of Croatia, OG 94/2013

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4.2. Waste from biological resources

According to data from Croatian Agency for Environment and Nature (CAEN), Table 21 presents the amounts of waste in period 2010-2017. As it can be seen, the amounts of total municipal waste produced in Croatia vary around 1.6 million tonnes each year. Following on Croatia's entering EU in 2013, the living standard started improving and the amounts of waste started to grow. Moreover, Croatian legislation framework was aligned with the EU waste framework, accepting the goals for waste management – the most important ones: increasing the share of separately collected waste up to 50% and reducing the share of biodegradable waste on landfills (Figure 17).

Table 21 Amount of total municipal waste generated in period 2010-2017[7]

Year	Amount of total produced waste [t]
2010	1,629,915
2011	1,645,295
2012	1,670,005
2013	1,720,758
2014	1,637,371
2015	1,653,918
2016	1,679,765
2017	1,716,444

In order to satisfy the goals set for Croatia by the EU, the share of separately collected biodegradable waste types and biodegradable waste that should be energy and/or materially recovered will increase (e.g. collected biowaste should be above 40% by 2022). Total waste generation per category for the period 2010-2017 is presented in Table 22. These amounts are related to biodegradable non-hazardous waste categories that could be considered for waste management within the principles of Bioeconomy. It should be mentioned that in period 2010-2013, biodegradable waste was considered only as a share of municipal waste – from 2014 a new *Methodology for determining composition and amounts of municipal, i.e. mixed municipal waste* by CAEN was introduced, where biodegradable waste was separated in specific waste categories (Figure 18).

Moreover, it should be noted that biodegradable waste in Croatia includes the following waste types: paper, cardboard, biowaste, textile and wood, etc. Since most of the aforementioned waste types are recyclable, which are planned to be treated in WMCs, the remaining waste type for energy and material recovery is biowaste.

[7] CAEN, Reports on municipal waste (2010-2017)

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Table 22 Municipal biodegradable waste amounts produced in Croatia in period 2010-2017[8]

Year	Amount of total produced waste [t]	Amount of landfilled waste [t]
2010	1,012,651	963,889
2011	1,017,519	937,375
2012	1,078,295	892,049
2013	1,103,593	870,434
2014	1,083,596	819,757
2015	1,070,783	828,564
2016	1,072,439	831,977
2017	1,091,066	801,238

Biowaste in Croatia is defined as biologically degradable waste from gardens and parks, food and kitchen waste from households, restaurants and retail and similar waste from production of food products. As waste management in Croatia is already oriented toward recycling of materials such as paper, cardboards, metals, etc., biowaste could be considered as a feedstock for Bioeconomy.

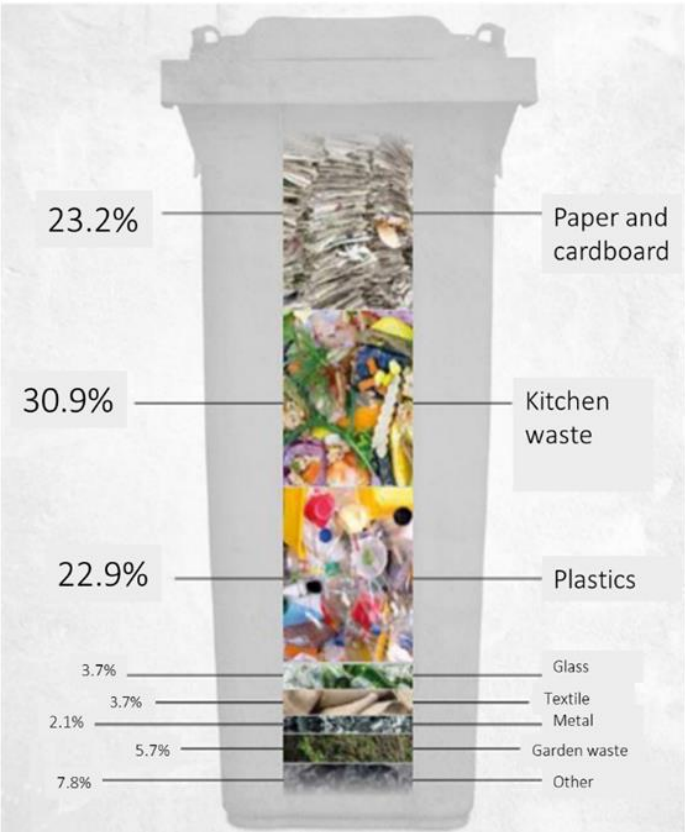

Figure 18 Estimated composition of mixed municipal waste in the Republic of Croatia in 2015

[8] CAEN, Reports on municipal waste (2010-2017)

Assessed amounts of produced biowaste from municipal waste do not differ greatly from 2012, and amount in average around 530,000 tonnes annually. The share of biowaste in mixed municipal waste is around 37.06%[9]. From this amount, around 13% is collected separately (71,046 t in 2017 (CAEN, 2017) and forwarded to recovery (composting, anaerobic digestion), while the rest ends up in landfills at this moment (around 450,000 t).

The S2BIOM figures on the biodegradable waste potential for 2020 are in the same line and estimate a total of 493 Ktonnes d.m. biowaste which is not far off the 530 Ktonnes mentioned above based on the 2012 and figure for the following years. The difference in total is probably related to the fact that S2BIOM figures were based on population numbers for 2020. In S2BIOM it is estimated that 290 Ktonnes of the biodegradable waste is already separately collected, while the remaining 40% remains in the mixed waste stream and requires separation after collection. As it can be seen from national data and reports, this number is not achieved.

There is another separate biodegradable waste flow of 70 Ktonnes d.m. of post-consumer wood. This biomass potential has so far not been included in the above totals and is an attractive source to further recycle in biomaterials, especially where it relates to the non-hazardous fraction. The larger fraction of hazardous post-consumer wood could at least go to energy generation. Current uses of this biowaste resource are:

- Energy recovery
- Recovery other than energy recovery - Backfilling

[9] Share of 37.06% is determined based on the defined composition of mixed municipal waste in Croatia, taking into account the following components: garden waste (5.68%), kitchen waste (30.93%), animal skin/bones (0.45%). Since wood component's origin is not known, it was not considered during the composition determining of biowaste share in mixed municipal waste.

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Table 23 Biodegradable waste potentials for Croatia (Ktonnes d.m.) as assessed in S2BIOM (Base potential/See Annex 2 for explanation of how these were assessed)

Ktonnes d.m. 2020 Base potential		Biowaste unseparately collected	Biowaste separately collected	Total	Hazardous post consumer wood	Non hazardous post consumer wood	Total
Name	R_code	5111	5112		5211	5212	
Primorsko-goranska županija	HR031	20	14	34	2	3	5
Ličko-senjska županija	HR032	3	2	6	0	1	1
Zadarska županija	HR033	12	8	20	1	2	3
Šibensko-kninska županija	HR034	7	5	12	1	1	2
Splitsko-dalmatinska županija	HR035	31	22	52	3	5	7
Istarska županija	HR036	14	10	24	1	2	3
Dubrovačko-neretvanska županija	HR037	8	6	14	1	1	2
Grad Zagreb	HR041	54	38	91	4	9	13
Zagrebačka županija	HR042	22	15	37	2	3	5
Krapinsko-zagorska županija	HR043	9	6	15	1	1	2
Varaždinska županija	HR044	12	8	20	1	2	3
Koprivničko-križevačka županija	HR045	8	5	13	1	1	2
Međimurska županija	HR046	8	5	13	1	1	2
Bjelovarsko-bilogorska županija	HR047	8	6	14	1	1	2
Virovitičko-podravska županija	HR048	6	4	10	0	1	1
Požeško-slavonska županija	HR049	5	4	9	0	1	1
Brodsko-posavska županija	HR04A	11	8	18	1	2	3
Osječko-baranjska županija	HR04B	21	14	35	2	3	5
Vukovarsko-srijemska županija	HR04C	12	8	21	1	2	3
Karlovačka županija	HR04D	9	6	15	1	1	2
Sisačko-moslavačka županija	HR04E	12	8	20	1	2	3
Total		**290**	**204**	**493**	**24**	**47**	**70**

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Additional feedstock that can be used within Bioeconomy is sewage sludge from wastewater treatment plants (WWTP). The amount of produced sewage sludge in Croatia is around 35,000-40,000 tonnes per year (around 20,452 tonnes of dry sludge matter) (Government of Republic of Croatia, 2017). Of that amount, around 50% of the sludge is produced by and located at the site of the Central Device for Wastewater Purification of the City of Zagreb. It is additionally estimated that, on a national level, around 1,100-2,000 tonnes of sludge are used for agricultural purposes and 110-200 are composted annually[10]. The remaining sludge is mostly landfilled. Although this potential for bioeconomy feedstock is relatively small, the amounts of sewage sludge will grow in the future with construction of WWTPs with higher wastewater treatment levels (Figure 19). If all future and planned WWTPs in Croatia would operate under full load, they would generate between 95,000 and 101,000 tonnes of sewage sludge dry matter per year (considering the production of 30 kg dry matter/person equivalent per year (Karagiannidis et al., 2011; data from WWTP Zagreb), which is a significant increase compared to current state.

However, currently an adequate management system for residual sludge from WWTPs is not established yet, primarily meaning the necessary infrastructure for treatment.

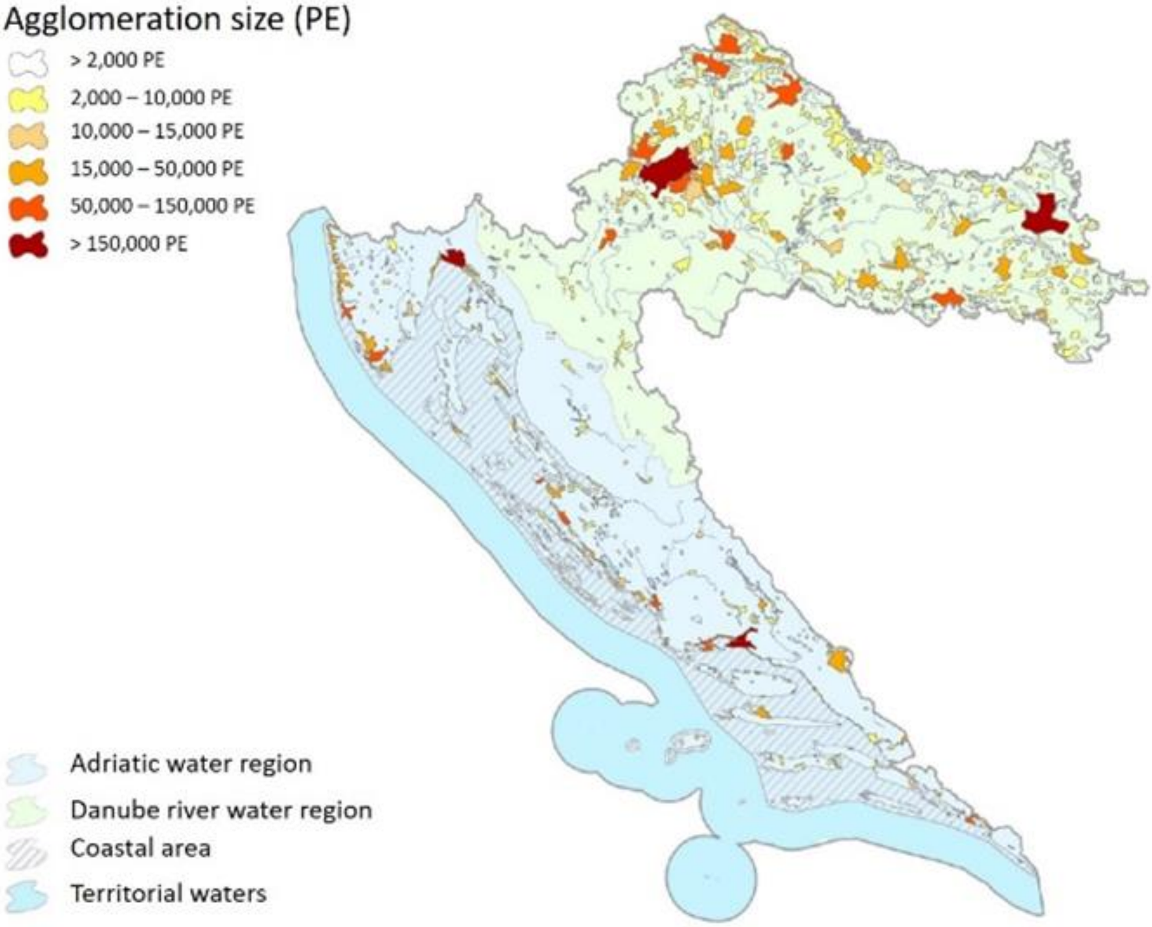

Figure 19 Spatial arrangement of agglomerations in Croatia (Đurđević et al., 2019)

[10] CAEN, Management of sewage sludge from WWTPs when sludge is used in agriculture, 2010-2017

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Waste cooking oil is collected in household and service sector, which is delivered to authorized companies that are recovering this type of waste. According to data from Environmental Protection and Energy Efficiency Fund (Government of Republic of Croatia, 2017), around 86,500 l (760 tonnes) of waste cooking oil is collected annually, from which 98% is recovered.

Regarding industrial waste, Croatia implements a "polluter pays" principle, which determines that the producer of waste has to manage its waste accordingly and properly. Waste amounts produced in the industry sector are defined in the *Polluter Register* (created in 2011), which includes hazardous and non-hazardous waste categories. Table 24 shows the amounts of industrial waste produced in period 2010-2017.

Table 24 Industrial waste amounts produced in Croatia in period 2012-2017[11]

Year	Non-hazardous waste produced [t]
2012	1,309,770.57
2013	1,377,847.86
2014	1,523,538.24
2015	1,844,367.98
2016	2,007,816.38
2017	1,780,089

[11] Polluter Registers for period 2012-2017

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4.3. Current waste treatment and unused potential estimates

4.3.1. Existing waste treatment facilities

According to the Waste Management Plan for Croatia, facilities for waste management are facilities for waste collection (recycling yards), facilities for waste treatment (incineration, AD plant, composting facilities, energy recovery) and WMCs.

Aerobic biological treatment of bio-waste by composting is conducted in 11 composting plants of a total capacity of around 103,397 t/year, of which, in 2016, 7 had a valid waste management permit.

In 2016, of the total 11 biogas facilities, 6 biogas facilities possessed the permit for anaerobic biological treatment of bio-waste, totalling a capacity of 234,800 t/year. An overview of locations of composting plants and biogas facilities in Croatia in 2016 is given in Figure 20, and an overview of the existing composting plant capacities in Table 25.

Currently the biodegradable treatment installations for compost mostly have one outlet and that is compost. But for investments in further installations and existing ones it would be good to create treatment chains that first win the energy in an anaerobic digestion installation and then use the digestate for compost generation. This combined treatment is attractive as it is more resource efficient particularly when options are also created to use the generated heat locally.

Table 25 Composting plants and their capacities in Croatia in period 2012-2017

Object location		Capacity [t]
Buzet*		7
Čakovec		10,000
Imbriovec		6,990
Kloštar Ivanić		27,300
Koprivnica		1,900
Krk		6,000
Perušić		1,200
Prelog		3,000
Zagreb	Jakuševec*	27,000
	Markuševac	10,000
	Jankomir	10,000
Total		103,397

*composting facility not active or does not have a valid permit

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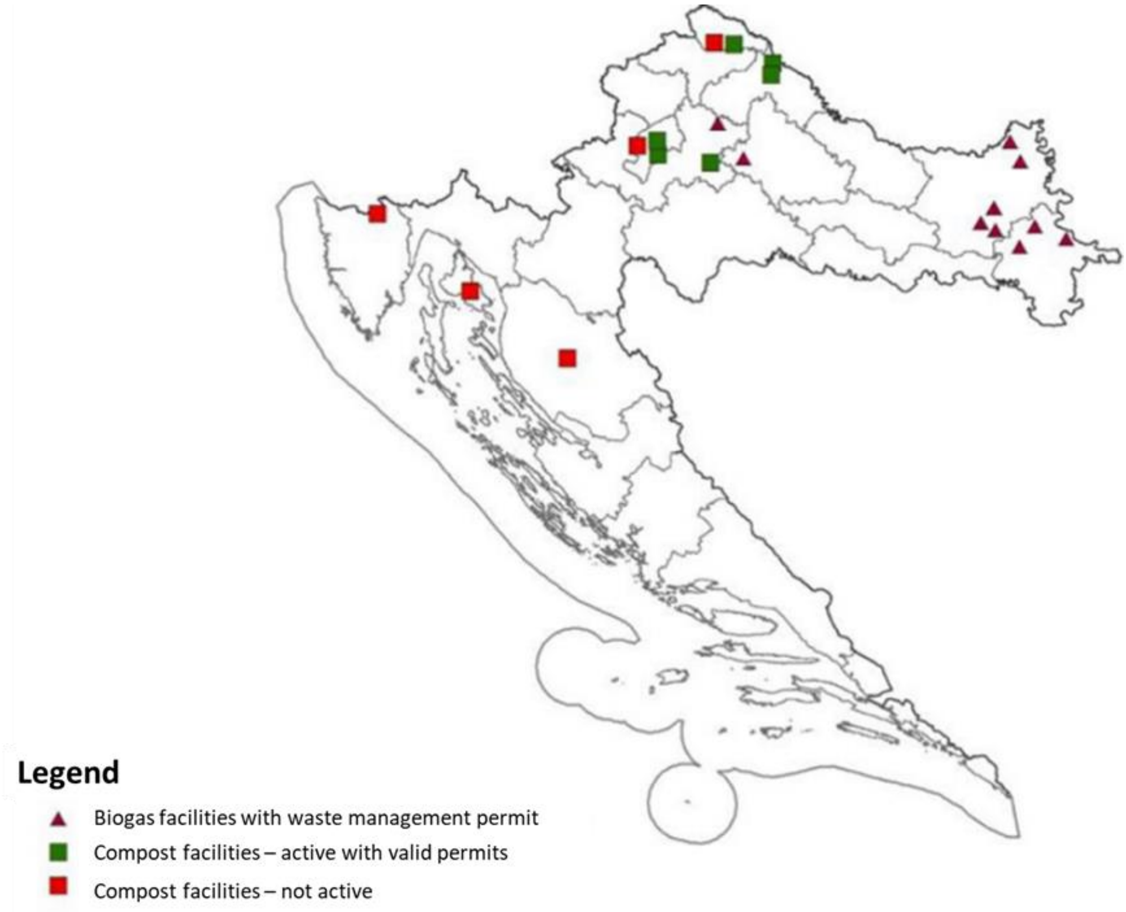

Figure 20 An overview of composting and biogas facilities in Croatia, 2016 (Government of Republic of Croatia, 2017)

The Waste Management Plan of Croatia foresees the construction of 13 WMCs for treatment of mixed municipal waste and other waste that was not previously recyclable (Figure 21). These plants are planned with the concept of mechanical-biological treatment technology (MBT), which contribute to the achievement of goals regarding the decrease of biodegradable waste landfilling and total quantities of landfilled waste, but it is not sufficient in regard to achieving the municipal waste recycling goals.

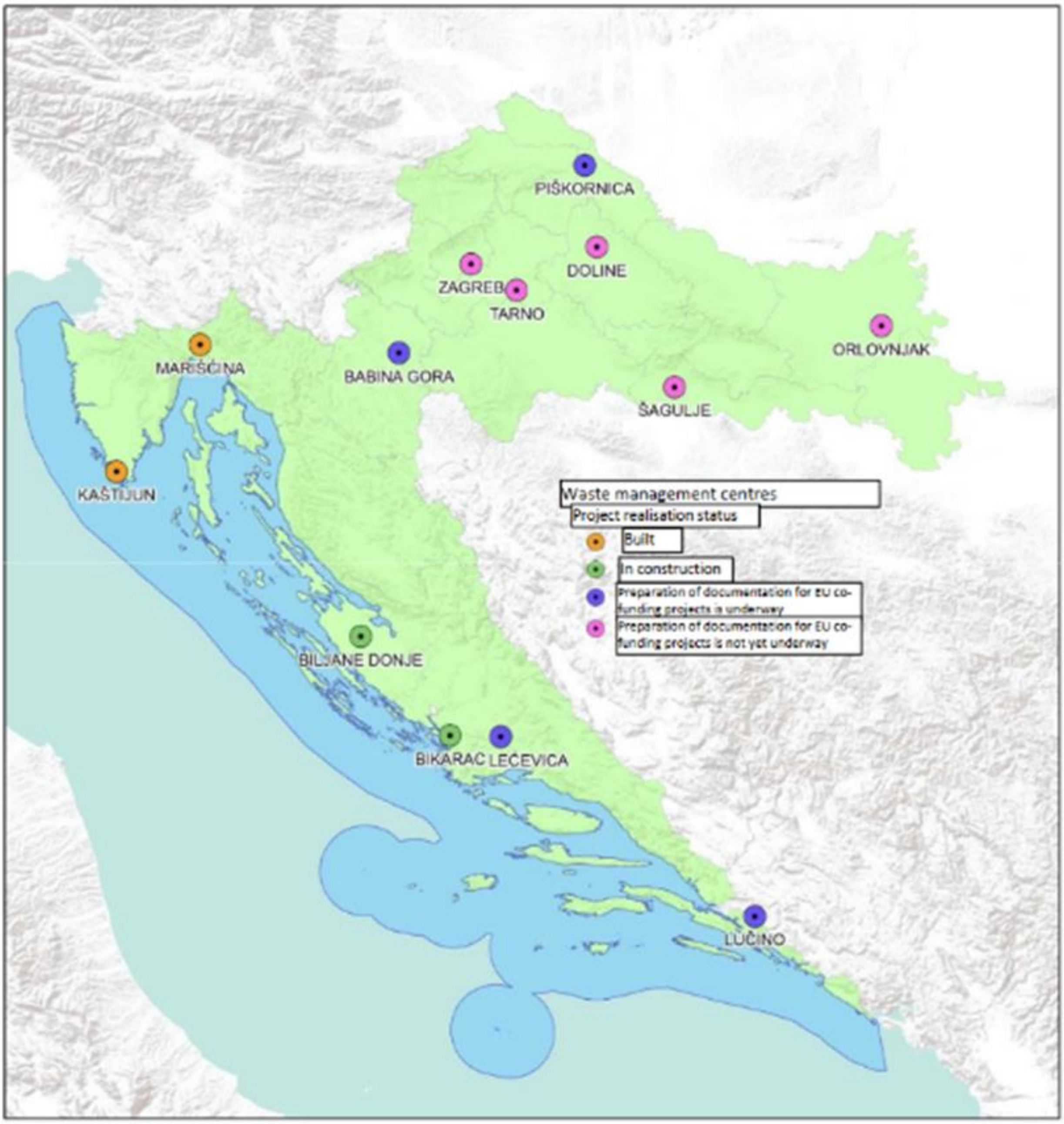

Figure 21 Position and capacity of planned WMCs according to the Waste Management Plan, according to the current status of realisation (Government of Republic of Croatia, 2017)

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Taking into consideration the mentioned portion and quantities of landfilled mixed municipal waste, we come to the conclusion that landfills in the Croatia annually receive almost 500,000 tonnes of biowaste (mostly biodegradable waste from gardens and parks on public surfaces), of which around 380,000 tonnes are estimated to be food waste (Table 26). On average, around 11% of total produced biowaste is separately collected, i.e. 60,000 tonnes, of which only a half is directed to recovery (composting, anaerobic digestion). Separate collection of biowaste in 2015 was conducted in 96 local self-governing units (17%), where quantities of separately collected biowaste from households are negligible.

Regarding industrial waste, the producer of waste has to manage it according to the regulatory framework. The amounts of produced and treated waste (industrial and municipal) are recorded in the *Polluter Register*, where waste management is presented per waste categories (industrial and municipal; hazardous and non-hazardous) and waste treatment. Table 26 shows the waste amounts treated (landfill, storage, preparation for reuse, energy/material recovery, etc.) in Croatia in the period 2010-2017.

Table 26 Waste amounts of treated waste (municipal and industrial) in Croatia for period 2010-2017[12]

Year	Non-hazardous waste produced [t]
2012	3,208,209.72
2013	3,445,549.11
2014	3,416,840.51
2015	3,723,968.58
2016	3,861,815.82
2017	3,918,487.00

[12] Polluter Registers for period 2010-2017

4.3.2. Estimates of waste potential

In order to calculate this potential, the following approach was implemented:

1. First the total waste generation per category of waste was considered
2. Then the waste treatment categories were identified per type of waste.
3. Considering that waste treatment options mentioned in documents related to waste management in Croatia include landfilling, storage, etc., these waste treatment categories are considered as potentials for waste utilization. So, the part already going to energy is also perceived to be available as part of the potential.

Table 26 shows that amounts of waste managed and treated surpass the amounts of municipal and industrial waste produced (additional waste is imported). These amounts include the waste that is landfilled, energy recovered, stored, etc. Therefore, the waste amounts mentioned for these purposes could be considered as a potential for energy and/or material recovery, instead of wasting their potential in landfills (without energy recovery).

In terms of municipal biodegradable waste, Figure 22 shows the amounts of biodegradable municipal waste that remain unused and that has the potential for energy and/or material recovery within the Bioeconomy principles.

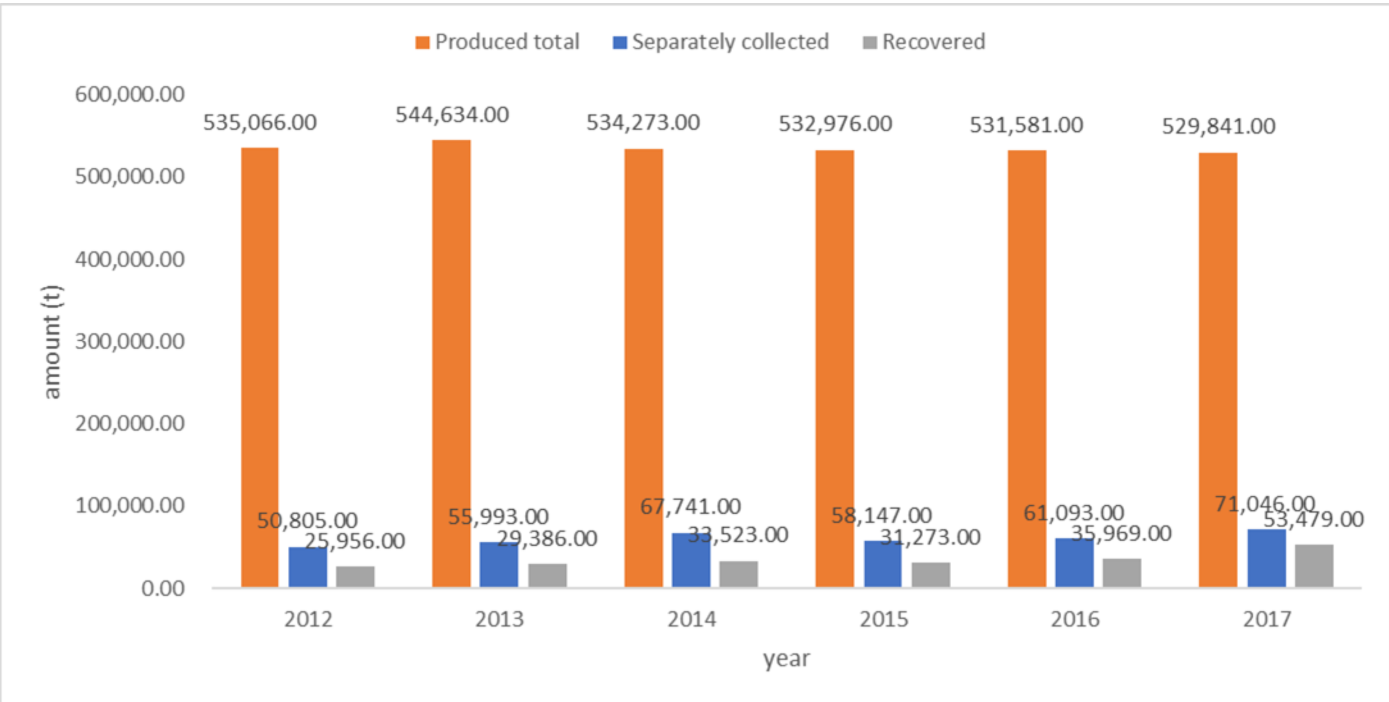

Figure 22 Quantities of produced, separately collected and recovered biowaste from municipal waste in Republic of Croatia, in the period from 2012 to 2015 (Government of Republic of Croatia, 2017)

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Total treated waste, considering treatment determined within *Polluter Register*, has the potential of unused waste in terms of landfilled waste that could be energy and/or materially recovered. The amounts that have the highest potential are presented in Table 27.

Table 27 Waste amounts with potential for energy and/or material recovery (municipal and industrial) in Croatia for period 2010-2017[13]

Year	Non-hazardous waste produced [t]
2012	1,938,822
2013	1,832,906
2014	1,687,761
2015	1,773,566
2016	1,764,643
2017	1,649,989

[13] Polluter Registers for period 2010-2017

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4.4. Summary and conclusions in relation to SWOT elements

Although waste management sector in Croatia improves each year (amounts sent to landfills decrease and reuse and recovery of waste increase), the progress is very slow. Moreover, raw materials are lost with lack of energy and material recovery systems. Generated waste per year amounts to cca 3.5 million tonnes of combined municipal and industrial waste (Table 26). This waste is treated in various ways, but the largest share is still going to landfill. Biodegradable waste is treated in three ways:

- Landfilling,
- Anaerobic digestion (biogas facilities – energy recovery) and
- Composting (composting facilities – material recovery).

Based on the aforementioned data, it can be seen that one of the strengths of waste management for the purpose utilization within Bioeconomy is the amount of waste generated, i.e. landfilled – therefore, usable for utilization. Moreover, the Croatian legislation and strategic framework are aligned with the EU legislation framework, which opens the possibilities of easier implementation of Circular Economy and Bioeconomy principles.

However, one of the weaknesses is the implementation of this legislation framework. Due to lack of knowledge on Bioeconomy principles and its possibilities, a significant amount of waste that could be energy/materially recovered ends up in landfills and unused. Moreover, the public awareness on waste management is very poor. Although there have been some projects related to increase of knowledge and awareness of citizens on waste management, the whole system is still in early phases in Croatia.

Following on all the above-mentioned data and information, there are a lot of opportunities for Bioeconomy principles implementation in Croatian waste management system. Biodegradable waste amounts, currently landfilled, could be utilised for energy and/or material recovery. Moreover, the concept of "Waste Market" should be implemented during this Waste Management Plan's period and the action plan on Bioeconomy oriented to support waste utilization in form of energy and material recovery. This will define the principles of financing and specific legislation (e.g. *Ordinance on by-products and end-of-waste status*) on waste management, which is currently missing or not developed enough. Additionally, the infrastructure construction is in implementation process, which means that there will be room for utilization of residual waste for energy and/or material recovery (within existing or new waste treatment facilities). Since investment for waste management infrastructure is mainly co-financed by the EU funds, there is an opportunity for implementation of Bioeconomy principles within Croatian waste management sector.

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Table 28 SWOT analysis for waste sector

Strengths	**Weaknesses**
Development of waste management infrastructure that can be used for energy and/or material recovery High existing potential for utilization which is currently still going to landfill Development of separate waste collection on household level	Implementation of legislation framework slow High collection and operational costs for waste management Lack of knowledge on Bioeconomy principles and its possibilities Significant amount of waste that could be energy/materially recovered ends up in landfills and unused Poor public awareness of waste separation/ management
Opportunities	**Threats**
Implementation of "Waste Market" Innovative ways of biodegradable waste utilization are possible given that this still needs to be largely build up Knowledge transfer from more advanced countries in EU Utilization of biodegradable waste that is currently landfilled Financing from EU funding, aligned with financing of waste management system (waste management centers)	Lack of recognition for the opportunities in waste utilization within Bioeconomy principles Backwardness and lack of change within legislation and strategic framework Negative public opinion in terms of waste separation, utilization for energy/recovery purposes Indifference of sector stakeholders

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5. Bio-based products industries and markets

5.1. Current bio-based industries

5.1.1. Bioplastics

Field of bioplastic materials in the Republic of Croatia is at a very early stage. Croatia's innovation performance over the last decade has fallen short of expectations. Based on information from HGK (Croatian Chamber of Commerce), there is no possibility at this moment to identify bioplastics manufacturers through existing official bases. Namely, producers and production of semi-finished and finished products are monitored by the NKD[14] for all polymers. The production of the polymer is monitored according to the type of material but unfortunately the production of biopolymers in the Republic of Croatia for now does not exist according to official data and statistics. However, there is a production of biopolymer bags produced by companies Weltplast, EcoCortec and Mi-plast in Croatia. The innovation system is operating below its potential, whether measured by the system's inputs, outputs or by the contribution of innovation to economic growth.

There are two major companies at the market that produce biodegradable films and foils, **EcoCortec** in Beli Manastir and **Weltplast** in Odra / Zagreb. In its production program, Eco Cortec offers products based on three types of biodegradable polymers – PLA, PHA and fossil-based biodegradable polymer, while Weltplast works with BASF biodegradable polymers.

EcoCortec d.o.o. specializes in developing and manufacturing value-added biodegradable/compostable flexible films that outperform non-degradable and other biodegradable materials currently on the market. EcoCortec strives to develop eco-efficient production of biodegradable films that combines new technology and high productivity with positive effect on environment. Installed production capacity is 5,000 tonnes/year, enabled by state-of-the-art extrusion, converting and regranulation equipment. Together with University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, EcoCortec have been involved in the CIP Eco-innovation project, funded by the European Union – MarineClean (Marine debris removal and preventing further litter entry), with the scope of developing plastic packaging material, degradable in seawater. Furthermore, EcoCortec is taking part as a project partner in Interreg Central Europe project BIOCOMPACK-CE.

Weltplast d.o.o. is producer of wide range of products, including pressure HDPE pipes, PP pipes for home installation and dressed packaging, industrial films and foils. Weltplast also offers a range of environmentally friendly products, under the EcoWelt brand. EcoWelt® products are completely biodegradable and compostable. Obtained by extrusion process of BASF raw materials. EcoWelt® packaging products fully comply with the requirements of EN 13 432, which establishes criteria for biodegradation and composting, as well as compost quality, and all harmonized with the European Directive 94/62/EC on packaging and packaging waste. Company also has recycling line installed.

[14] NKD-Nacionalna klasifikacija djelatnosti (eng. National Classification of Economic Activity)

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Mi-plast d.o.o Company's main activity is the processing of LDPE and HDPE materials, bio polymers, packaging and production of these materials, as well as regeneration and recycling of these materials. The products obtained by processing of polyolefins and bio-materials are mainly used in the construction sector, agriculture and in retail sector. These products are: agriculture mulch, shopping bags, garbage bags, construction film foils, laminated foils etc. The company is placing its products mainly to the countries in the South Eastern Europe, Slovenia and Italy. Mi-plast d.o.o. works on the research and development of biodegradable biopolymer-based materials and participate in numerous research projects within the EU's R&D and Innovation Programs - FP7, Horizon2020, Life + ESIF. CIRC-PACK, RefuCoat, Afterlife, RES URBIS, PULPACKTION are just few projects that Mi-plast ltd. conducts in Croatia in field of bio-based research and development framework.

5.1.2. Wood processing industry

Spačva d.d. leading timber industry in Croatia in terms of size, organization, approach to management and transparency of operations. It currently employs 850 workers, making it one of the largest employers in the timber industry, Vukovar-Srijem County and Vinkovci. It produces only final products, mostly in oak, which it primarily exports. The products can be purchased in 30 countries around the world, with the most important markets being France, Italy and Germany.

5.1.3. Food and feed ingredients industries

The **Podravka** Group is a multinational group that through subsidiaries and representative offices operates in 25 countries on five continents (Europe, North America, Asia, Africa and Australia). Significant business Podravka Group has in Croatia, Slovenia, Bosnia and Herzegovina, Russia and Poland. It operates in two main business segments: food and pharmaceuticals. In the last decade Podravka takes on the role of the leading food brand company in Southeast, Central and Eastern Europe. The food sector is participating in the international market, in more than fifty countries on five continents.

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Figure 23 Main brands of Podravka company

Vindija Group is vertically integrated dairy and meat processing plant but with diversified portfolio including smart drinks and food. It encompasses 14 companies, out of which 8 are based in Croatia and 6 in neighbouring countries. It employs a workforce of more than 4,000 and makes an annual turnover of EUR 400 million. The company is proactive for accessing foreign markets with all international systems of quality: ISO 9001, HACCP, HALAL, KOSHER, IFS and BRC have been implemented into the production lines.

The "Vindija Quality" sign unites more than 1,000 different products into seventeen brand names, out of which 'z bregov, Cekin and Vindon are the most familiar with consumers.

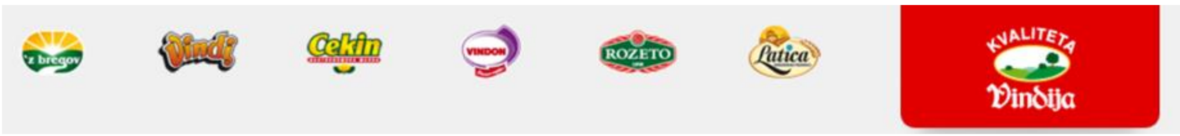

Figure 24 Main brand names in Vindija Group

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5.1.4. Pharmaceutical and cosmetic industry

Belupo d.d. company produces prescription and over-the-counter products including herbal remedies, nutritional supplements, cosmetics and OTC medicines. Belupo is a leading manufacturer in the cardiovascular and dermatology program in the Republic of Croatia. It is strategically oriented to increase exports and develop new products that meet the needs of a demanding foreign market, so it develops and grows in the countries of Central and Eastern Europe where it has its own representative offices and companies. Today, Belupo operates in 18 European pharmaceutical markets, except in Croatia.

Magdis d.o.o. has perfected pharmaceutical processes and advanced manufacturing processes by profiling in one of the leading Croatian service providers of dietetic and cosmetic products, as well as pharmacy and medical raw materials and products. In addition to manufacturing, the company is continuously engaged in the research and development of new products, and systematically invests in research and development, as well as the construction of a modern manufacturing facility. In October 2018, Magdis successfully completed the acquisition of Neva d.o.o. from Atlantic Group and becomes the largest regional cosmetics manufacturer with an impressive portfolio of brands (with Biobaza, Plidenta, Melem, Rosal, Pitroid, Dipterol, Ralon, Asebon, Asepsolete, Sumifen and others).

Figure 25 Main brands in Magdis company

Saponia d.d. is a leading detergent and hygiene industry with a tradition of more than 120 years. Saponia offers to the market more than 500 different products separated in three basic product groups: detergents for mass consumption (laundry detergents, fabric softeners, dish detergents, cleaning agents), personal hygiene program (toothpastes, toothbrushes, soaps, shampoos, baby care products, sun tanning products) and agents for industrial and institution use (products for cleaning and disinfection in various institutions and industrial corporations). There is a new line of products, Nature's best which is oriented to generation of products with higher content of natural ingredients.

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5.1.5. Valorisation of secondary materials from waste sector

Agroproteinka d.d. is a company with a 60-year-long tradition in collecting and managing animal by-products, which has been turning to production of renewable energy sources in the last decade. As a part of the global vision of environment protection, in 2008 Agroproteinka started collecting waste edible oil, which is transported to their plants for physical pre-treatment. Waste edible oil is a huge resource of renewable energy sources – it is used for obtaining biodiesel, a fuel for diesel engines. As citizens' awareness grows, and Croatia's responsibilities as an EU member increase, quantity of recycled oil grows day by day. Agroproteinka sells purified oil on the EU market. In 2017 started a pilot project for collecting waste edible oil, which was launched on 30 selected retail outlets in central Croatia (retail outlets owned by INA d.d.).

Regeneracija d.o.o. is doing business in accordance with the world trends. The high environmental awareness of the company is manifested in the positive organization of the production process based on the principles of sustainable development. From fibres obtained from the treatment of waste textile Regeneracija produce floor protection in construction works. In this sector Regeneracija is in top of European industry leaders. Project on textile material recycling "EKO – EKO" had two stages: the economy stage (EKOnomija) which has enabled to produce raw materials and resulted in the reduction of the disposal of our waste into the environment and other textile industry waste. The second stage – ecology (EKOlogija) – includes the processing of the total amount of gathered textile waste in the Republic of Croatia.

Gumiimpex-GRP d.d. is the first company in Croatia to start recycling waste (used) car tires in 2005. Gumiimpex-GRP is the only NEXT TREAD (Goodyear) and RECAMIC (Michelin) partner in Croatia.

Vetropack Straža d.d. manufactures, sells and distributes glass packaging in the markets of Croatia, Slovenia, Bosnia and Herzegovina, Serbia, Montenegro, Macedonia, as well as in the markets of other Southeast European countries. Today, Vectropack glass factories consistently rely on recycling. In Vetropack, glass karst has become the most important raw material for glass production: at the Group level, on average, karst accounts for 60 % of total raw materials. Of utmost importance to Vectropack Group is a collection of glass waste by colour. For example, only white glass karst is used to produce white glass.

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5.2. Advanced bio-based initiatives: demo and pilot plants and major innovation activities

In order to stimulate the development and growth of the Croatian economy, the Government of the Republic of Croatia has decided to group all public, private and scientific research representatives in innovative sectors, all to strengthen the competitiveness of Croatian companies, and consequently the Croatian economy and society. Clusters of competitiveness in the Republic of Croatia are conceived as non-profit organisations that bring together all the best businessmen in a certain sector - small, medium and large entrepreneurs, representatives of regional and local government and research institutions, in order to establish synergy and cooperation to strengthen the competitiveness of economic sectors at national level. The Agency for Investments and Competitiveness and the Ministry of Economy, Entrepreneurship and Crafts played an essential role in identifying, supporting and creating Croatian Competitiveness Clusters.

13 Croatian Clusters of competitiveness have been established:

1. Croatian Food and Processing Sector competitiveness cluster
2. Croatian Competitiveness Cluster for the Wood Processing Sector
3. Croatian Competitiveness Cluster for the Automotive Sector
4. Croatian Competitiveness Cluster for Creative and Cultural Industries
5. Croatian Cluster of Competitiveness of Textile, Leather and Footwear Industry
6. Croatian Defense Industry Cluster
7. Croatian Construction Industry Competitiveness Cluster
8. Croatian Competitiveness Cluster for the Power and Manufacturing Machinery and Technologies Sector
9. Croatian Health Industry Competitiveness Cluster
10. Croatian Competitiveness Cluster of the Chemical, Plastics and Rubber Industries
11. Croatian ICT Industry Competitiveness Cluster
12. Croatian Maritime Industry competitiveness cluster
13. Croatian competitiveness cluster for the Personalized Medicine

Croatia is a full member of **BIOEAST Initiative** – Central and Eastern European initiative for knowledge-based agriculture, aquaculture and forestry in the bioeconomy. An open initiative started by the Visegrad Group Countries: Czech Republic, Hungary, Poland, Slovakia, and joined by Bulgaria, Croatia, Latvia, Lithuania, Republic of Estonia, Romania, Slovenia. The initiative offers a shared strategic research and innovation framework for working towards sustainable bioeconomies in the Central and Eastern European (CEE) countries. One of the main objectives is to initiate cooperation and the development of knowledge-based policies: establish a multi-stakeholder network and cluster at European level to facilitate joint actions, backed up by a renewed commitment to closer cooperation at both the political and operational levels through close personal contacts and communication between the countries concerned at the operational level, as well as initiate strategies: create a cross-sectorial approach for the development of a national circular and bioeconomy strategy. Also, the Initiative seeks to provide an evidence base: establish data-driven support for the implementation of policies through the creation of an interoperable, fully integrated observing and forecasting system. This would promote continuous, long-term observation based on open data structures to guarantee easy access.

There are **no commercial bio-refineries** in Croatia, which is the most outstanding barrier to a more bio-based (domestic) industry at large. Oil company INA, together with Faculty of Agriculture, University of Zagreb, is participating in another BBI JU funded project, GRACE "GRowing Advanced industrial Crops on marginal lands for biorEfineries" of which the main goal is to produce sustainable products with a strong market potential, to guarantee a reliable and affordable supply of sustainably produced biomass, and to better link biomass producers with the processing industry. To avoid competition with food and feed crops, miscanthus and hemp are cultivated on areas that have been polluted, for example by heavy metals or are unattractive for food production due to lower yields. INA has been given the role of the leader of the demonstration chain for testing the cultivation of Miscanthus hybrids on marginal and lower quality soils for processing into advanced bioethanol. At this point, the first harvest of the miscanthus energy crop was completed at the beginning of the year. The miscanthus (lat. Miscanthus x giganteus) was planted on a demonstration farm in Rugvica in cooperation with BC Institute, near Zagreb, and this season's harvest yielded around 30 tonnes of biomass.

Collected biomass was sent to Clariant, a focused and innovative speciality chemical company to their pre-commercial sunliquid®plant in Straubing, Germany, for processing and conversion into lignocellulosic sugars and ethanol. The results give cause for optimism as they show that the sunliquid®technology can successfully convert miscanthus into lignocellulosic sugars and ethanol.

5.3. Future Biomass valorisation options

At present, BBI project GRACE is ongoing in Croatia represented by two project partners, Faculty of Agriculture, University of Zagreb and INA d.d., oil company in 44.8% ownership of Croatian government. The GRACE project is demonstrating the biobased value chains below in 10 Demo Cases presented in Figure 26. INA d.d. is interested in developing a biorefinery based on project result in Croatia.

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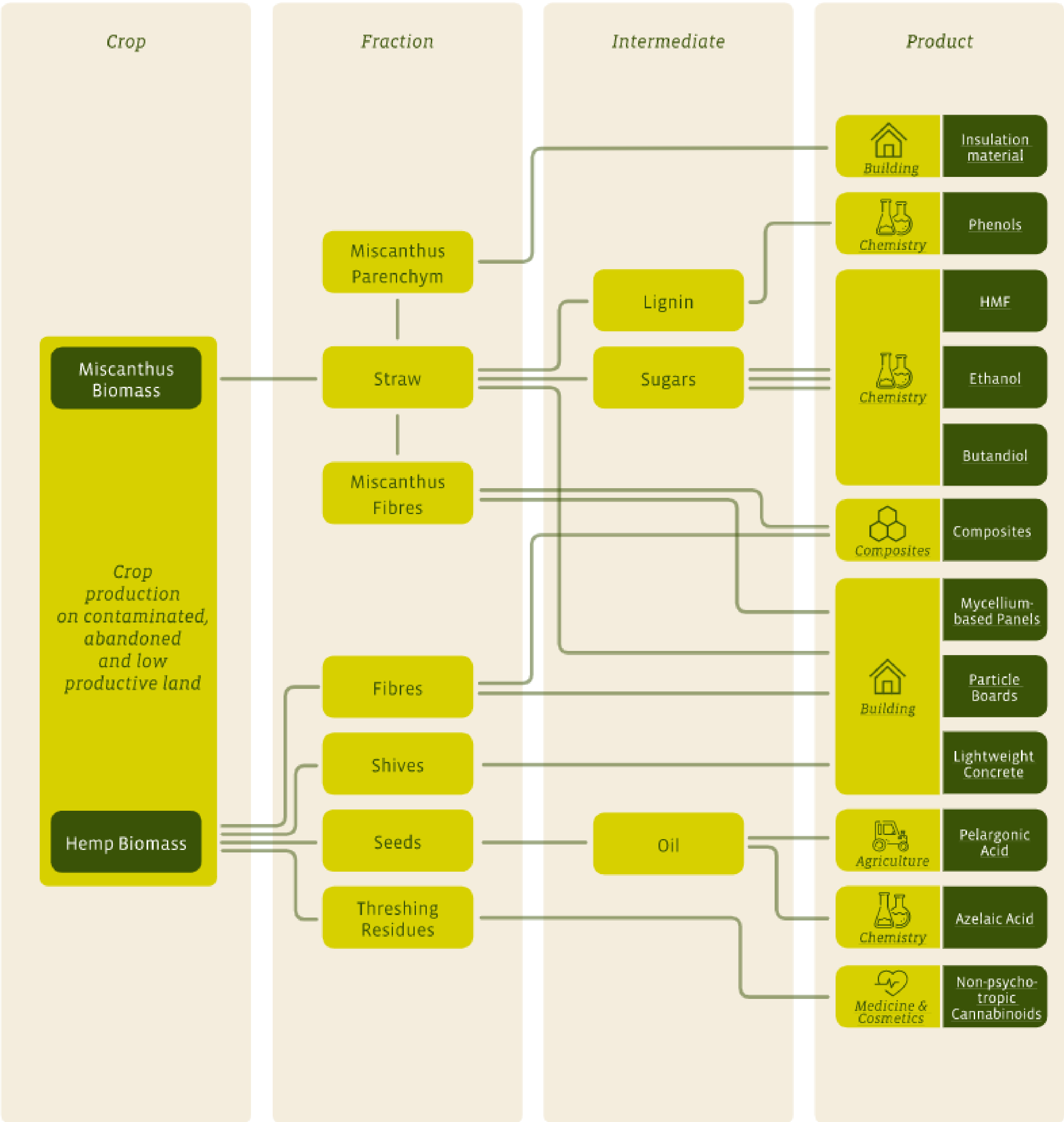

Figure 26 Value chains in GRACE project

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5.4. Summary and conclusions in relation to SWOT elements

Croatia has great potential to foster bioeconomy development. With a strong foothold in wood processing and food and beverage industry, there is room for significant innovation activities and new business models. Regional leaders in bio-based activities such as Mi-plast d.o.o. and Weltplast d.o.o. could be used as examples of good practice. However, there is still a lack of communication between important stakeholders and leaders of the bioeconomy sector in Croatia, which could be a potential for improvement and closing the circle of material and energy management in each company.

Table 29 SWOT analysis of bio-based products, industries and markets

Strengths	**Weaknesses**
Strong academic community Interest in following global and European trends On-topic ongoing research projects Start-up entrepreneurship Proof Of Concept programme	The insufficient connection and research projects between academia, public and the private sector A small rate of high TRL (6-9) research/development infrastructure The loss of engineers (scientists, engineers, doctors, …) due to "brain drain" No PPP in other sectors except construction Development based on individual approach
Opportunities	**Threats**
Pilot projects to connect the academy community and private investors The underexploited potential of agricultural residues Connection with the tourism sector Programmes to keep the young people in the country (decrease "brain drain") PPP expanding to other sectors Expansion of food and processing industry, pharmaceutical and cosmetic industry into bio-based products and marketsFinancing from EU funding, aligned with financing of waste management system (waste management centers)	The loss of experts (and young people) due to rising competitiveness in other countries The loss of start-up companies due to lack of recognition of the legislative framework Lack of recognition of quality projects

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6. Infrastructure, logistics and energy sector

6.1. Existing industrial hubs and harbours

Three major Pan-European corridors pass through Croatia and make it the shortest route between Western Europe and Asia, Eastern Europe and the Mediterranean. Located in Southeast Europe, bordered by Italy, Slovenia, Hungary, Serbia, Bosnia and Herzegovina and Montenegro, Croatia is perfectly positioned for reaching the EU market as well as the markets of Southeast Europe.

Transport in Croatia relies on several main modes, including transportation by road, rail, water and air. Road transport incorporates a comprehensive network of state, county and local routes augmented by a network of highways for long-distance travelling.

Water transport can be divided into sea, based on the ports of Rijeka, Ploče, Split and Zadar, and river transport, based on Sava, Danube and, to a lesser extent, Drava. Croatian ports annually reload about 20 million tonnes of cargo and transport more than 16 million passengers (Table 30).

Table 30 Maritime transport statistics in Croatia[15]

Year		2016	2017	2018
Cargo [t]		18,551,030	20,797,543	21,572,694
Passengers [person]	**arrival**	16,398,962	17,171,859	17,872,846
	departure	14,584,374	15,351,342	16,101,093

Croatian ports are integrated into a comprehensive network of European transport corridors, which represents a growth potential that allows the inclusion of trade flows to the intra-European and world markets, as well as the transformation of port systems in modern logistics and distribution of economic centres.

Six major ports (Rijeka, Zadar, Šibenik, Split, Ploče and Dubrovnik) are located along the mainland coast, and all are declared ports of special (international) economic interests for the Republic of Croatia (Figure 27) (Božičević, 2008). Croatian seaports are conveniently positioned to facilitate maritime transport between Central and Eastern Europe and Southern Asia, Australia and Oceania and Europe (via the Suez Canal). They enable shortening of voyages by 5-8 days, or by a minimum of 2,000 km compared to north European ports. Currently, on the EU market, Adriatic ports take only 3% of total freight. Therefore, there is a vast potential to increase freight transport of all Adriatic ports.

[15] www.dzs.hr

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Figure 27 Maritime transport statistics in Croatia

The further development of Ports of Rijeka and Ploče depends partially on the development of their connections to the railways. The most important joint interest project for cargo maritime sector is the development and reconstruction of railway section from Rijeka to Hungary while further railway development in Bosnia and Herzegovina is of crucial importance for the development of the port of Ploče. Ports Pula, Zadar, Šibenik, Split, Dubrovnik and Ploče are classified as comprehensive ports on the Trans-European Transport Network (TEN-T).

Regarding inland waterways, Croatia's network stretches 804 km, 287 km of which is a part of an international waterway network[16]. Croatia lies on the important Danube waterway, one of Europe's main cargo transport routes which is a part of the Pan-European Corridor VII, which connects Croatia with the North Sea and the Black Sea. The major ports are Vukovar on the Danube, Osijek on Drava River, Sisak and Slavonski Brod on Sava River (Figure 28).

[16] http://www.investcroatia.hr/investors-guide/infrastructure/river-transport/

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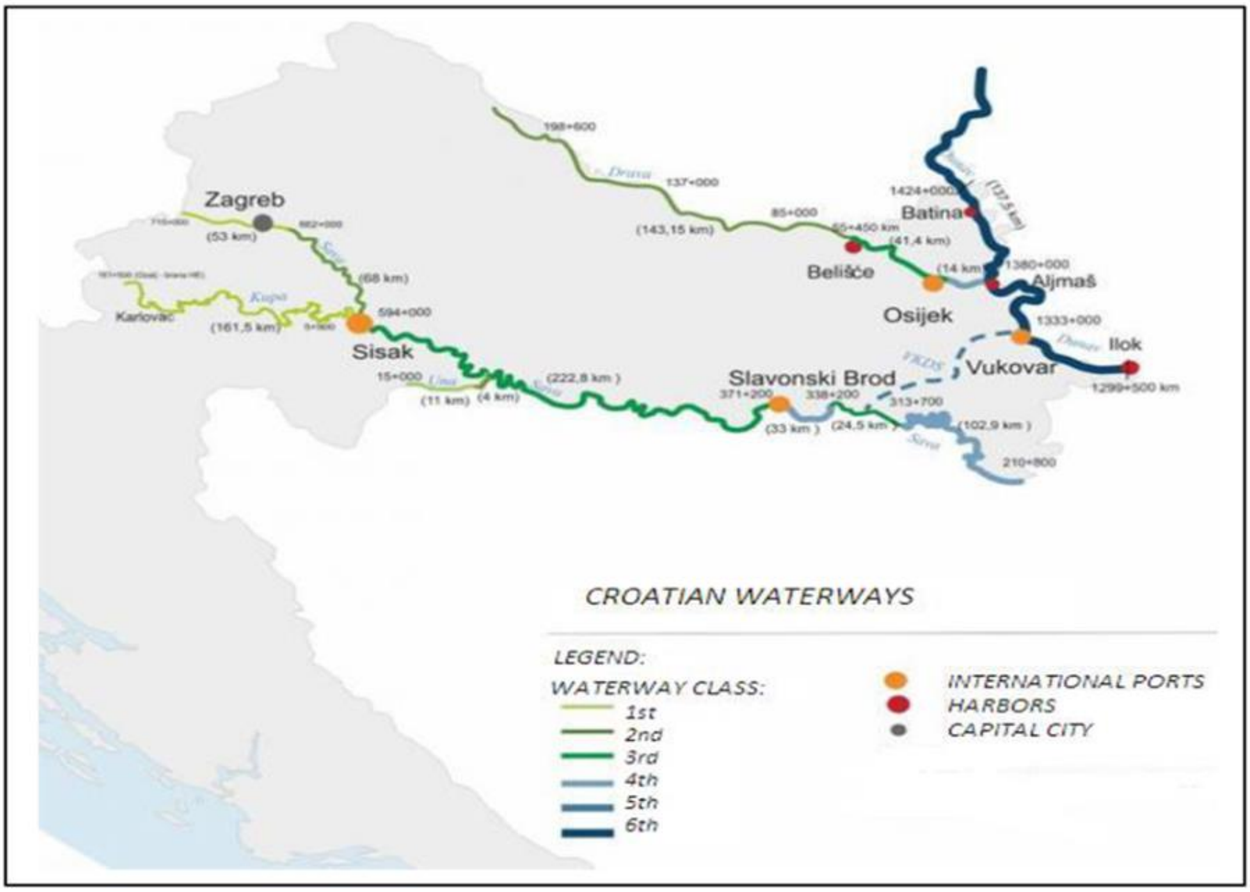

Figure 28 River transport on main Croatian inland waterways (Valleyo Saarmiento et al., 2016)

The Croatian network of inland waterways represents a significant, but at the same time, completely unexploited part of national values of Croatia. This mean of transport has a high potential for increase if appropriately managed (Table 31).

Table 31 Transport of Goods on Inland Waterways in Croatia in tonnes[17]

Year	2016			2017			2018		
	Total	National transport	International transport	Total	National transport	International transport	Total	National transport	International transport
	[t]								
Total	677,549	96,439	581,110	574,236	57,525	516,711	591,667	72,470	519,197

[17] www.dzs.hr

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Large scale bio-based production chains require transportation of large volumes of materials, i.e. the supply of biomass and the export of (intermediate) products. The only cheap options for the transportation of large volumes are waterways and railways. Experts indicated that hubs are essential for establishing successful biorefineries. In 2017, Croatia had 1,300 registered industrial hubs, from which around 450 were industrially active, with cca. 70,000 employees. These hubs are divided by size to: 0-1,000 m²; 1,001-10,000 m²; 10,001-100,000 m² and 100,001-1,000,000 m² and founded by local municipalities and three counties. Their geographical distribution is presented in Figure 29, with the allocation of closest airports and harbours.

Figure 29 Map of Croatian industrial hubs[18]

[18] http://investcroatia.gov.hr/en/zone/

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6.2. Existing railway

The Croatian railway network comprises 2,617 km. A good ratio of railway line kilometres and the country's population (1,556 people per kilometre) ranks the Republic of Croatia among developed European countries. However, 90% are single-track lines and only 36% of lines are electrified. Almost 55% of the network is dedicated to those lines that are significant for international transport. Of this 2,604 km, only 5.4% is capable of reaching speeds between 141 and 160 km/h, 17% has a maximum speed above 100 km/h, and 37,5% has maximum speeds below 60 km/h (Valleyo Sarmiento et al., 2016).

Three companies control the Croatian railway network: HŽ Infrastruktura Ltd., HŽ Putnički prijevoz Ltd. and HŽ Cargo Ltd.. On its network, it maintains 546 stations and stops, 1,503 level crossings, 109 tunnels and 544 bridges (Figure 30). Many of these facilities are also protected cultural heritage. HŽ Infrastruktura is responsible for traffic management and operation, for rehabilitation, maintenance and construction of railway infrastructure, which is a public good in general use. On average, around 709 passenger and 120 freight trains operate on the network on a daily basis.

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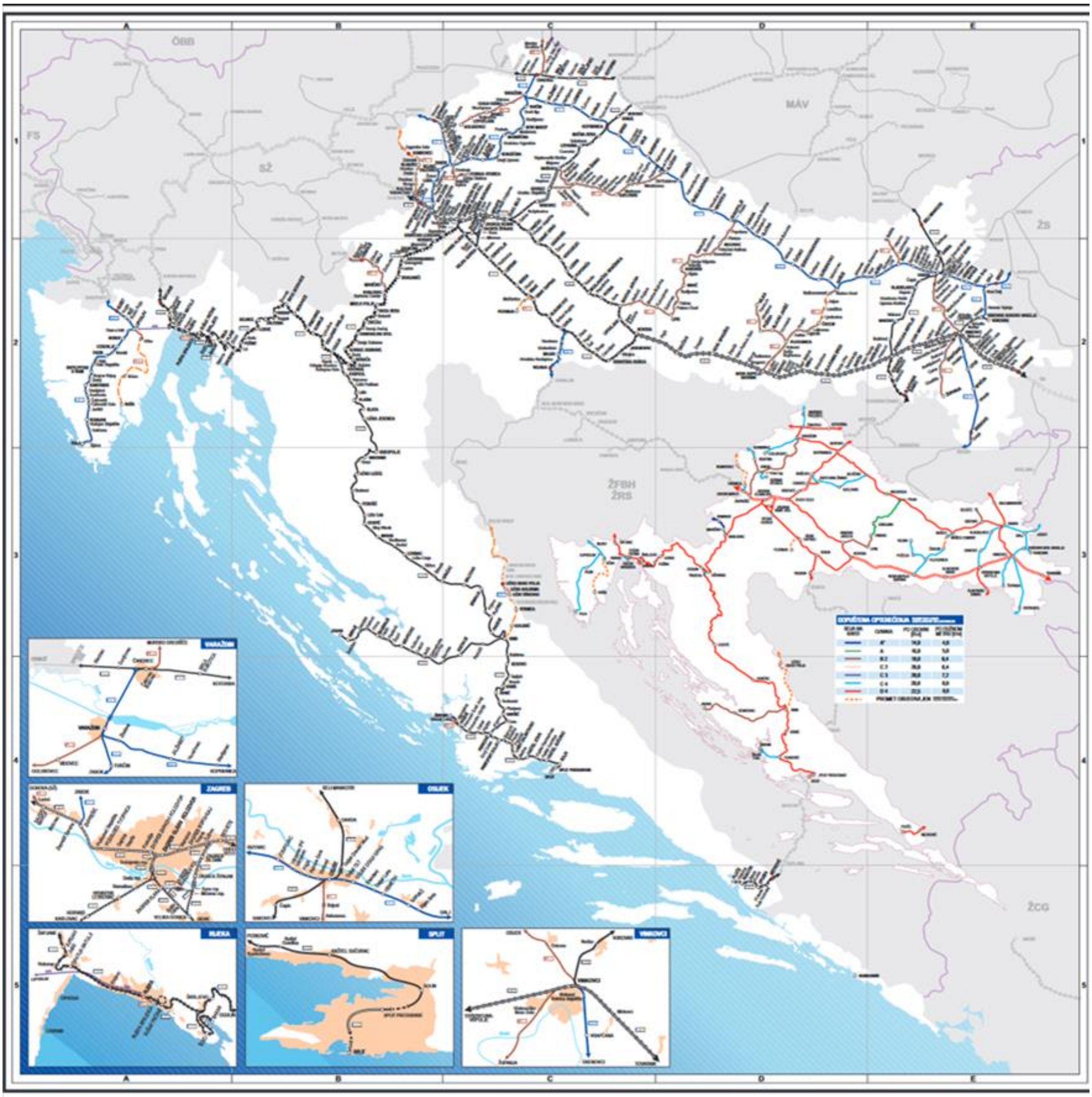

Figure 30 Railway network map with stations and stops in Croatia[19]

The access to the Croatian railway network for freight operators was liberalized on July 1, 2013, upon Croatia's EU accession. Currently, there are eleven operators on the network, ten freight and one passenger operator.

With Croatian accession to EU, the authorities were determined to reform and rethink the transport system, with special focus on railway transport. In order to benefit from the future financial support of the EU, they have to provide the right

[19] http://www.eng.hzinfra.hr/?page_id=418

administrative capacity to manage funds and elaborate viable projects. Thus, Croatia is eligible for structural and cohesion funds and EC approved investment plans for the cohesion policy worth EUR 449.4 Million.

Therefore, work on three international corridors were intensified (Figure 31):

- TEN-T core and comprehensive network (Pan EuropeanCorridor X), Salzburg –Thessaloniki;
- TEN-T Mediterranean corridor (Pan Europeancorridor Vb), Budapest – Rijeka and
- TEN-T comprehensive network (Pan Europeancorridor Vc), Budapest –Ploče.

Figure 31 Pan-European corridors in Croatia (Božičević, 2008)

Moreover, modernisation of the remaining sections of the TEN-T core network lines according to their functionality is underway. Croatia, the European Union and the World Bank are expected to invest more than 3 billion EUR in designing, renovating and upgrading Croatian railway infrastructure over the next ten years. HŽ Infrastruktura is carrying out

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projects with investments promoted by the government and local authorities aimed to encourage cross-border railway traffic. There are 18 projects in different stages of progress, of which only the Gradec - Sv. Ivan Žabno line has been finished (Figure 32)[20].

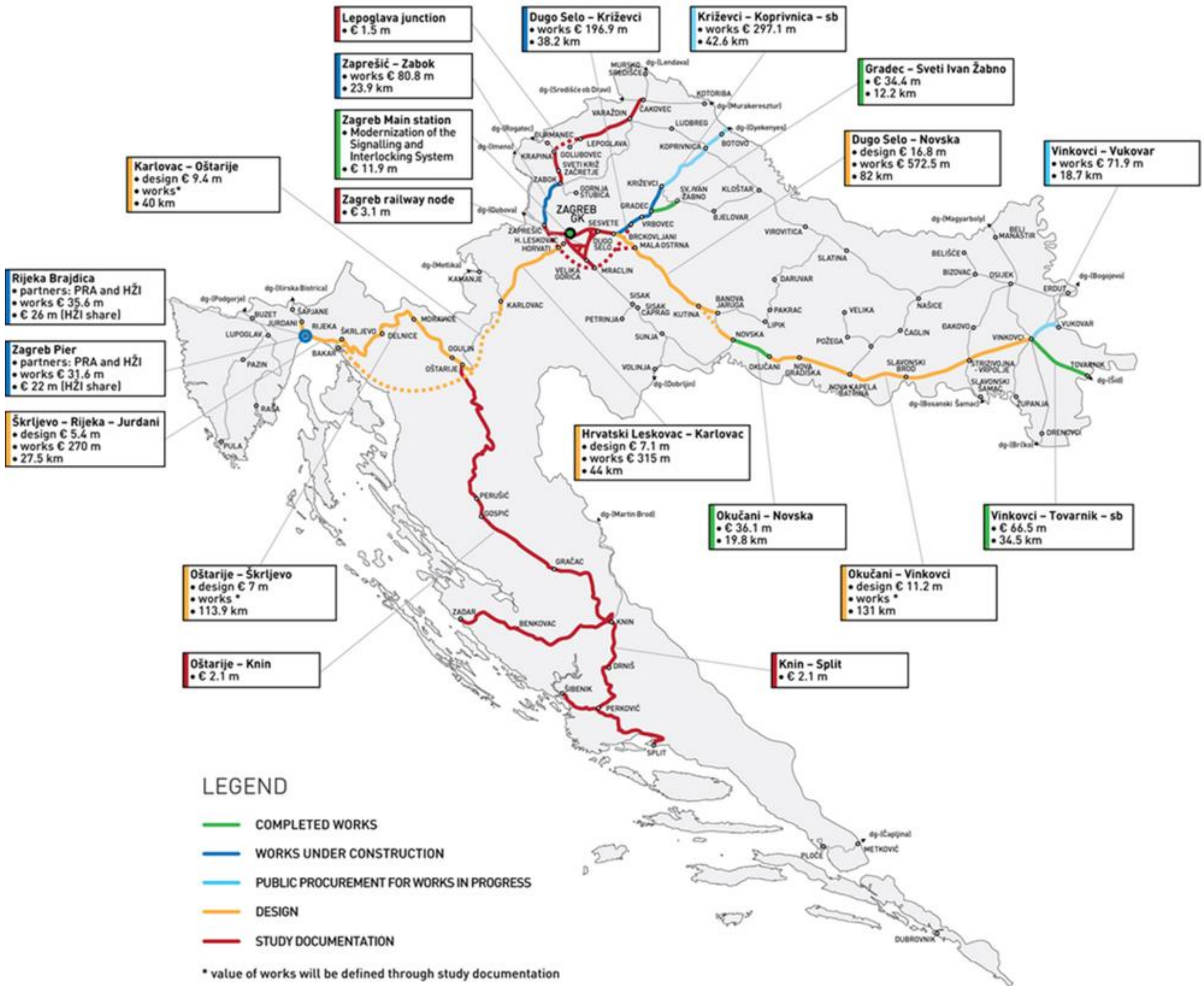

Figure 32 Status of EU projects on modernizing the railway structure in Croatia[21]

[20] http://www.eng.hzinfra.hr/?page_id=321
[21] http://www.eng.hzinfra.hr/?page_id=321

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Additionally, HŽ Infrastruktura is using funds from Connecting Europe Facility (CEF), a EU funding instrument for the financial framework 2014 – 2020. It supports the development of high performing, sustainable and efficiently interconnected trans-European infrastructure networks in the fields of transport, energy and digital services. The following project are funded by CEF:

- Reconstruction of the existing track and construction of the second track on the section Križevci – Koprivnica – state border;
- Preparation of project and other documentation for construction of second track, upgrade and modernization of the railway line on rail section Škrljevo – Rijeka – Jurdani;
- Designs for the upgrade of the railway section Oštarije – Škrljevo;
- Preparation of design documentation for the reconstruction of the Okučani – Vinkovci railway section;
- Port of Rijeka multimodal platform development and interconnection to Adriatic Gate container terminal;
- Upgrade of the Rijeka Port infrastructure – Zagreb Pier container terminal;
- Technical assistance to improve capacity building for railway infrastructure manager in Croatia;
- Enhancing the cooperation between Railway Infrastructure Managers for better safety management.

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6.3. Existing road infrastructure

Regarding its integration in international traffic, it should be emphasized that Croatia is already today, with its highly developed motorway network (90% constructed), close to high European standards regarding international road connections.

The road network of the Republic of Croatia is being managed by Hrvatske autoceste Ltd., Hrvatske ceste Ltd. and concession societies (societies for the construction, maintenance and operation of motorways and objects for toll collection).

Hrvatske Autoceste is a company that operates the largest motorway network in the Republic of Croatia.

This network of 918.5 km includes the following motorways:

- Motorway A1 Zagreb - Split - Dubrovnik (Bosiljevo - Split - Ploče - Karamatići) of 415.3 km;
- Motorway A3 Bregana - Zagreb - Lipovac of 306.4 km;
- Motorway A4 Zagreb - Goričan of 96.9 km;
- Motorway A5 Beli Manastir -Osijek - Svilaj of 58.7 km;
- Motorway A10 B&H border - Ploče of 8.5 km;
- Motorway A11 Zagreb - Sisak of 32.7 km.

One behalf and for the account of the company Autocesta Rijeka - Zagreb d.d. the company maintains and collects toll on the following motorways whose total length is 187.03 km:

- A6 Rijeka - Zagreb of 146.5 km;
- A7 Rupa - Križišće of 28 km;
- Rijeka town bypass
- D102 Krk Bridge of 12.53 km.

Included in this network are several important European traffic roads (Figure 33):

- TEN-T Mediterranean corridor/PanEuropean corridor;
- Vb: Rijeka-Zagreb-Budapest; TEN-T comprehensive network/Pan-European corridor;
- Vc: Ploce- Sarajevo- Osijek- Budapest; TEN-T core network/Pan-European corridor;
- X: Salzburg- Ljubljana- Zagreb- Beograd- Niš- Skopje- Veles-Thessaloniki;
- TEN-T comprehensive network/Pan-European corridor;
- Xa: Graz- Maribor- Zagreb

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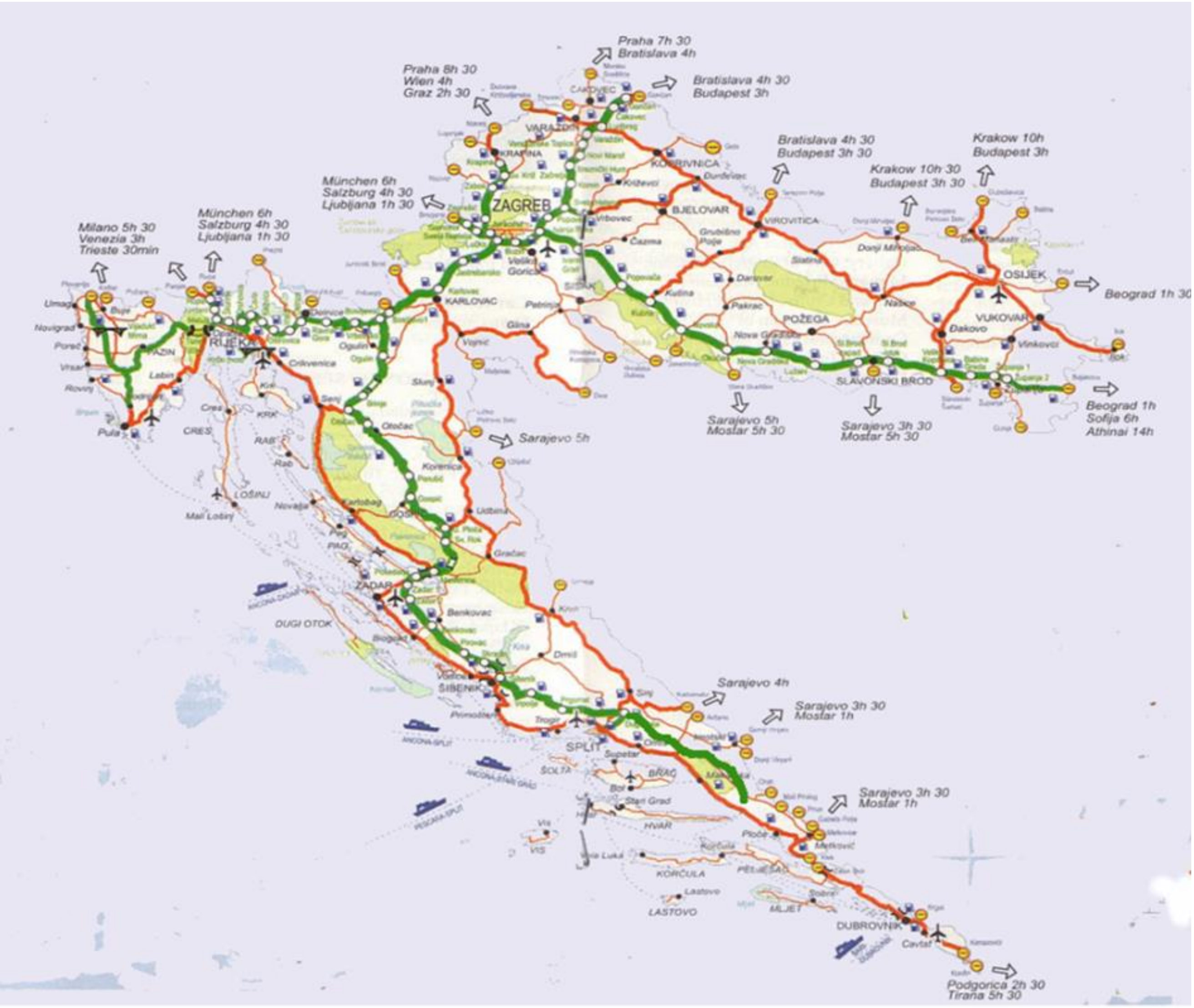

Figure 33 Road Network Map (Valleyo et al., 2016)

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The construction and opening to traffic of motorway sections exceeding 600 km over the past 14 years has contributed to the overall traffic safety on motorways in the Republic of Croatia and has decreased the number of accidents in the whole country

Moreover, modernisation and construction of new roads are funded mainly through EU funds, through Connecting Europe Facility (CEF) and Operational Programme Competitiveness and Cohesion (OPCC) funds. The latter has three ongoing projects: Svilaj bridge, Crocodile 2 and Crocodile 3, which are international projects between the EU-Member States from the Central European region, who are working together to improve cross-border traffic and transport.

Tourism is of major importance for the Croatian economy, and most tourists come on vacation in Croatia in their cars. Without adequate roads, the traffic would get rather jammed during the summer months. For this reason, and as a means for stimulating urgently needed economic growth, highways have become indispensable for the sustainable development of this country. Croatia already has a considerable highway density for a country that still has to cope with the consequences of Communism and the recent war. As of 2006, Croatia has 28,344 kilometres of roads. Out of these, there is 23,979 km of paved and 4,365 km of unpaved roadways.

6.4. Energy sector

The Croatian power system comprises plants and facilities for electricity production, transmission and distribution in the territory of the Republic of Croatia. For the security reasons, quality of supply and exchange of electricity, the Croatian power system is interconnected with the systems of neighbouring countries, and together with them, it is connected into the synchronous network of continental Europe (Figure 34).

By its size, the Croatian power system is one of the smallest power systems in Europe. Due to its geographical position and location of generating plants, electricity is transported for most of the year from the south to the north and vice versa, and from the north toward the east.

The Croatian power system is a control area by Croatian Transmission System Operator (HOPS). Together with the Slovenian power system and the power system of Bosnia and Herzegovina it constitutes the control block SLO – HR – BIH within the ENTSO-E association.

Croatia has an electrification rate of 100% with well-developed grid and all settlements connected to the power grid. Grid connection is not an obstacle for using biomass as an energy source for electricity, although with the market premium system, the focus will be generating electricity from fuel-less sources: PV and wind.

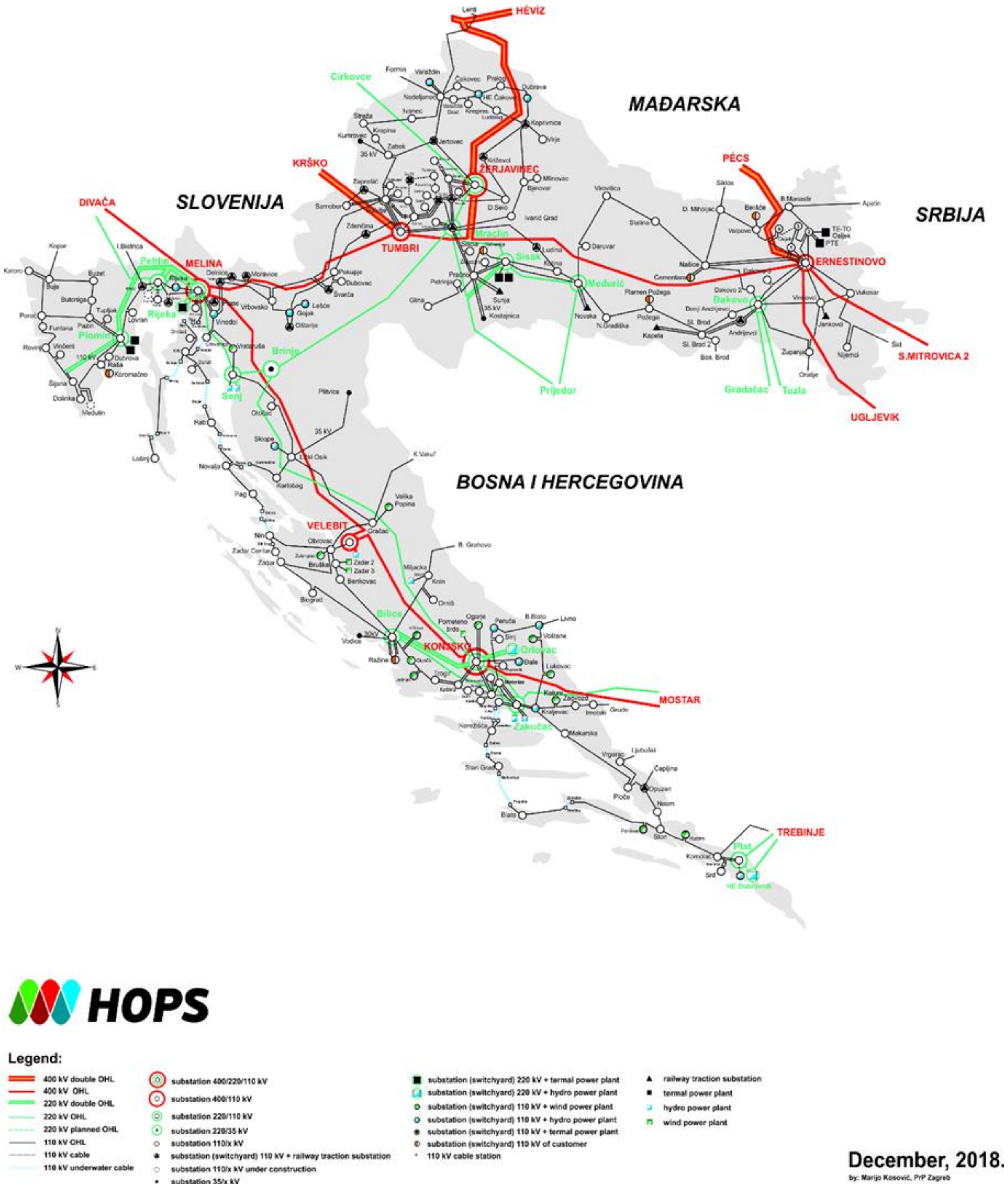

Figure 34 Croatian transmission network[22]

[22] https://www.hops.hr/en/system-scheme

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The Energy Act and the Electricity Market Act create the fundamental conditions for an electricity market in Croatia. Preparing and adopting Electricity Market Rules and other secondary legislative acts have created the condition for the operation and the gradual opening of the market.

	2013.	2014.	2015.	2016.	2017.	2018.	2018./17.	2013.-18.
	PJ						%	
Ogrjevno drvo i biomasa Fuel Wood and Biomass	61,45	57,97	64,19	64,15	64,67	63,06	-2,5	0,5
Sirova nafta Crude Oil	25,71	25,38	28,62	31,47	31,79	31,26	-1,7	4,0
Prirodni plin Natural Gas	63,11	60,52	61,61	57,52	51,76	43,07	-16,8	-7,4
Vodne snage Hydro Power	84,92	88,99	61,63	65,63	53,81	66,98	24,5	-4,6
Toplinska energija Heat	0,63	0,52	0,62	0,66	0,67	0,63	-5,4	0,1
Obnovljivi izvori Renewables	7,71	10,58	10,99	12,90	16,10	16,21	0,7	16,0
UKUPNO TOTAL	**243,53**	**243,95**	**227,65**	**232,33**	**218,79**	**221,21**	**1,1**	**-1,9**

Figure 35 Primary energy production in Croatia (EIHP, 2018)

However, Croatia is still dependent on energy import from neighbouring countries. Even though the import related to specific energy sources has fallen, it has increased in terms of biomass (Figure 36).

Krško nuclear power plant in Slovenia, of which HEP owns 50%, also contributes to Croatia's electricity supply but is counted under imports in the statistics (electricity).

This fact presents a significant potential for bioeconomy, where agricultural, forestry and waste biomass could contribute in terms of energy generation and covering of growing energy demand in Croatia.

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	2013.	2014.	2015.	2016.	2017.	2018.	2018./17.	2013.-18.
	PJ						%	
Ugljen i koks Coal and Coke	36,10	30,46	32,11	34,49	22,57	19,69	-12,7	-11,4
Sirova nafta Crude Oil	105,12	79,05	99,41	107,32	120,33	126,63	5,2	3,8
Derivati nafte Petroleum Products	60,30	80,78	85,49	83,33	93,48	86,75	-7,2	7,5
Prirodni plin Natural Gas	43,19	39,19	36,33	44,01	63,10	55,05	-12,8	5,0
Električna energija Electricity	24,64	24,40	31,93	31,43	34,16	26,66	-22,0	1,6
Drvo i biomasa Biomass	0,42	0,49	1,18	1,21	1,54	3,02	96,3	48,5
UKUPNO TOTAL	**269,77**	**254,36**	**286,45**	**301,80**	**335,16**	**317,79**	**-5,2**	**3,3**

Figure 36 Energy import in Croatia (EIHP, 2018)

Additionally, the energy sector represents the largest source of greenhouse gas (GHG) emissions, and climate change are one of the greatest threats to modern mankind. According to preliminary calculation results for 2018., emissions from stationary and non-stationary energy sources amounted to 15.3 million tonnes of CO_2, which is 5.8% less compared to the previous year (Ministry of Environment and Energy, 2019).

Energy transition, which is closely linked with economic development, in Croatia represents a possibility for industrial development and new job openings. To ensure a complete insight in expected and wanted of energy sector development, Ministry of environmental protection and energy ordered the creation of "*Energy Development Strategy for the Republic of Croatia for 2030 with a view to 2050*", in which renewable energy sources utilization is promoted, including biomass and biodegradable waste. In terms of bioeconomy, this is a significant step forward, where bio-based resources can contribute to energy production in Croatia, without jeopardising its sustainability.

6.5. Summary and conclusions in relation to SWOT elements

Croatia is a significant part of Trans-European Transport Network (TEN-T), with 6 important coastal ports (Rijeka, Zadar, Šibenik, Split, Ploče and Dubrovnik) and a significant potential within inland marine ports. Its strategic geographical position is exceptionally favourable for supplying markets in Central and Eastern Europe and has a high impact on markets as a leader in the Balkan area. The aforementioned ports are well connected with railway and especially the road network.

Furthermore, the energy sector is well connected all along the country, but also with neighbouring countries through the transmission network.

However, all of the above requires modernization, especially railway and inland marine ports network. The railways are being modernized because since the disintegration of Yugoslavia there have been hardly any investment in railway infrastructure. Since it is a quality way to connect industry hubs, along with the inland and marine ports, it has great potential for utilization as a transport mean for bioeconomy purposes (transport of feedstock, new products, biofuels, etc.).

Additionally, the Croatian network of inland waterways represents a significant, but at the same time, completely unexploited part of the national values of Croatia. The overall length of the current inland waterways in Croatia is 1016.8 km, of which 601.2 km has been integrated into the European network of inland waterways of international importance. The Danube part of the Republic of Croatia's inland waterways system forms a part of the RhineDanube Corridor. Ports Vukovar and Slavonski Brod are classified as core ports in the EU TEN-T network but require modernization and investments. They also have the potential for utilization for bioeconomy purposes in terms of transporting feedstock and new products. In conclusion, it can be seen that railway and inland marine ports have potential to increase and strengthen Croatia's connection with the EU through bioeconomy.

Furthermore, by implementing bioeconomy in Croatia, the energy sector would benefit the most, since the import of biomass as an energy source has lately significantly increased (96.3%). Utilizing biomass (agricultural, forestry and waste) as an energy source, within sustainability limits, would prove to have a significant impact on energy autonomy and balance.

Table 32 summarises SWOT elements of Infrastructure, logistics and energy sector of Croatia.

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Table 32 SWOT analysis of the infrastructure, logistics and energy sector in Croatia

Strengths	**Weaknesses**
Good connection with European countries (Central and Eastern Europe) Well-developed motorway network Established positions in EU hinterland transport Access to the sea Large number of existing and active industrial hubs	Underdeveloped railway system Lack of sustainable planning Lack of inland waterway network Lack of modernised transportation networks
Opportunities	**Threats**
Increasing investments in ports, railways, airports and other transportation infrastructure Central position of Croatia in TEN corridors (Baltic-Adriatic and Mediterranean corridors) Established strong position of road network (esp. in freight transport)	Worrying condition of the state road network Condition of the railway network. Increased congestion in the country during tourist seasons Competition from other corridors (Slovenia, Hungary, Italy) Competition from other ports (Trieste, Venice)

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7. Skills, education, research and innovation potential

7.1. Availability of skilled operators and service providers

Labour relations in Croatia are regulated by laws, collective agreements and individual contracts, and rules adopted by employers. The Labour Act is in harmony with the conventions of the International Labour Organisation.

The main issues regulated by this Act are:

- legal basis for labour relations – a work contract (the form, duration and obligatory contents of the contract are defined);
- working hours (40 hours per week), overtime work, annual and other leave (at least 4 weeks), forms of maternity protection and protection of employees who are temporarily or permanently disabled;
- salaries: the employer must not pay a lesser amount than what is stated in the collective agreement (salary system discrimination is prohibited);
- the procedure for the termination of a work contract, i.e. related procedures, the reasons for a regular and irregular notice of dismissal (there are provisions for obligatory severance programs in the cases when an employer considers downsizing for organisational, economic or technical reasons), periods of notice;
- assuming employment rights and regulations (decision making on rights and regulations and their legal protection);
- employees' rights in the decision-making process with respect to their economic and social rights and interests (through representatives on the employee council).

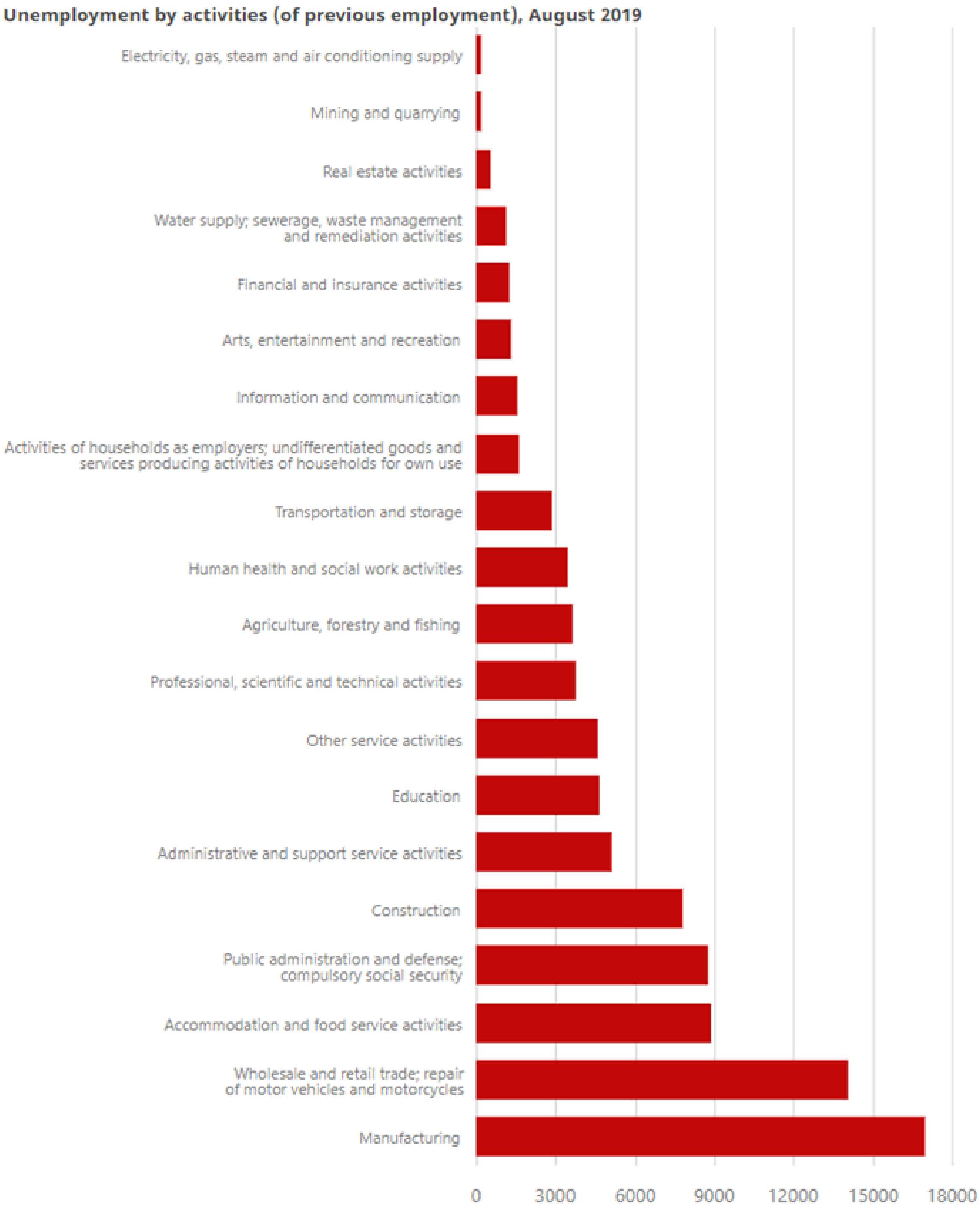

Figure 37 Unemployment by activities in Croatia for 2019

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7.2. Research infrastructure

The most research infrastructure equipment, related to bio-based industrial development may be found at the Institute Ruđer Bošković, Faculty of Agriculture, Faculty of Chemical Engineering and Technology, Faculty of Science, Faculty of Food Technology and Biotechnology, Faculty of Forestry all as members of the University of Zagreb. Furthermore, there are Faculty of Food Technology Osijek and Faculty of Agrobiotechnical Sciences Osijek. Alongside with Universities in Croatia, there are few research institutions more included in bio-based development.

As a leading and largest Croatia's multidisciplinary research centre, **Institute Ruđer Bošković** employs valuable human capital of over 890 employees, of which over 500 scientists and researchers in 82 laboratories are engaged in research in the fields of theoretical and experimental physics, material physics and chemistry, electronics, physical chemistry, organic chemistry and biochemistry, molecular biology and biomedicine, and exploring the sea and the environment. The Institute participates in numerous internationally and nationally funded and internationally peer-reviewed research projects such as those under Horizon 2020, IAEA, FP7, HRZZ, NATO, NSF, ICGEB and other foreign scientific foundations. The Institute is currently implementing more than 200 projects, with more than half of the total funding being funded by EU projects and other international sources. The Institute also houses capital research equipment worth over HRK 100 million.

The Ruđer Bošković Institute (IRB), together with the Institute of Physics (IF), is a partner of the Polytechnic of Slavonski Brod (VUSB) on the project 'Adaptation of Vegetable Crops to New Agro-Meteorological Conditions in Slavonia' worth almost HRK 3 million. Also, Institute is participating in BIO-ECOnomy Research Driven Innovation (BIOECO-R.D.I.) which aims at developing a Regional Innovation System for the Adriatic-Ionian area based on a structured bio-economy sector through the development of Research Driven Innovation (R.D.I.) strategy at regional and transnational level

Faculty of Agriculture, University of Zagreb has over 100 national and international ongoing scientific projects which contribute to sustainable agriculture development. With 9 undergraduate, 14 graduate and 4 postgraduate programmes in the field of agriculture Faculty of Agriculture aims to become the leading scientific institution in this region. The FAZ owns 6 experiment stations which are used for teaching, scientific research and technical activities. The FAZ has also started setting up a Bioengineering Research Center (ABIC) in the city of Zagreb. Furthermore, there are 28 laboratories among which is a Reference laboratory for milk and dairy products (RL). Faculty of Agriculture Council decided to establish the research-teaching station in the open state hunting ground no. III / 29 - "PROLOM", located in the Sisačko-moslavačka county in 1999. Research-teaching station is named "Ban Josip Jelačić" and is intended for teaching work and scientific research related to wildlife management, hunting, fishing, beekeeping, mushroom science, meat production, botany, horticulture and other related areas.

The hunting ground is mountain character, includes extreme western slopes and parts of the massif Zrinski Mts., and it was named after the forest complex Prolom. The hunting ground is located south of the town Glina, and the total area is 7,709 hectares. The research station is equipped with accommodation facilities, science research unit and laboratory and all the necessary agricultural machinery for management of hunting ground.

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Faculty of Agriculture is a project partner in ongoing BBI funded project GRACE which is made up of a unique consortium of 22 partners from both academia and industry and also includes SME's, farmers and an industrial cluster. The ten value chains under consideration will be demonstrated from the production of the crop through to the final bio-based product. Also, the environmental, economic and social sustainability of each value chain will be assessed using LCSA tools.

Faculty of Chemical Engineering and Technology, University of Zagreb is an educational institution in the scientific field of chemical engineering and scientific field of chemistry realizes projects for the real sector and in cooperation with industry. Priority research topics are environmental protection and environmental management, development of new advanced materials and sustainable technologies, energy, alternative and renewable energy sources, development of new drugs and industrial biotransformations. Furthermore, Faculty participates in designs processes, devices, equipment, facilities and complex systems, produces studies, audits studies and projects, provides consulting services, supervises construction works, ensures and controls the quality of materials and processes, issues certificates of properties of materials etc.

Faculty of Food Technology and Biotechnology, University of Zagreb, is a leading scientific research and teaching institution in the Republic of Croatia in the field of biotechnology, nutritional technology and nutrition. At the Faculty, students can enrol in one of three undergraduate studies: the study of Food Technology, the study of Nutrition and the study of Biotechnology. Currently, 27 laboratories are fully equipped. The Faculty also conducts professional activities through the Food Control Centre as an accredited laboratory for the control of the safety and quality of food and general use products in the European Union. Within the institution of higher education, the Centre has been one of the first spin-off companies for over 50 years. Since 2007, the Centre for Food Technology and Biotechnology has been operating in Zadar at the Faculty of Food Technology and Biotechnology. The Centre has a Laboratory for Drying Processes and Stability Monitoring of Bioactive Compounds and since 2015 a Laboratory for Honey Quality Control. The Faculty actively participates in numerous research and networking projects funded both from national and international funds.

At the moment, around one hundred research projects are being carried out at **Faculty of Electrical Engineering and Computing (FER)**, University of Zagreb, as well as dozens of cooperation projects with the economic sector. According to the European Commission report, FER is among leading institutions in Croatia in terms of successful applications for EU funds. FER represent an IT component to bioeconomy development in Croatia through different projects such as *Structured organic farming using autonomous greenhouse robots* (HRZZ), *Extraction of bioactive compounds from Mediterranean plants with 'green solvents' using high voltage discharge* (HRZZ), *Agrivi Smart - Increase Potato Growing Productivity Using Machine Learning Algorithms* (EFRR) and *Improving the efficiency of manufacturing through research and development of innovative ICT services to increase energy efficiency - ComEnergy* (EFRR). Their contribution to smart farming could be seen through collaboration with Agrivi. Agrivi and Faculty of Electrical Engineering and Computing in Zagreb have signed an agreement with the Ministry of Economy, Entrepreneurship and Crafts to award a HRK 6.35 million grant for the development of the Agrivi SMART self-learning system, which will by help of AI advise farmers on how to use agronomic practices to achieve optimal yields and increase in profitability.

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Croatian Forestry Institute actively contributes to the research community in Croatia with numerous collaborations in the geographical region in the forestry-based sector. Some of the projects conducted at Forestry institute in the bio-based sector are *Capacity Building in Forest Policy and Governance in Western Balkan Region* (CAPABAL), *Sustainable Wood for Europe* - ROSEWOOD, *Modelling of forest stocks and carbon flows and risks under future climate scenarios* (MODFLUX) etc.

Institute for Development and International Relations conduct a BBI fund project: Innovative VET for key competences in the emerging field of forest bioeconomy (VET4BioECONOMY) which aims to increase the knowledge and provide key competences in forest bioeconomy to forestry-related professionals and increase current base of VET and LLL programmes in partner countries with innovative and comprehensive forest bioeconomy training programme.

Energy Institute Hrvoje Požar with its Department for RES, energy efficiency and climate protection established a leadership role when it comes to bioeconomy development in Croatia. There are numerous projects funded from Horizon2020, Interreg Programme, IEA, COST, World Bank, as well as nationally funded projects. Currently, one Horizon2020 project should be emphasized in the context of bioeconomy - Advancing Sustainable Circular Bioeconomy in Central and Eastern European countries: BIOEASTsUP. This project aims at supporting the BIOEAST Initiative in developing Bioeconomy Strategies and Action Plans in the Central and Eastern European countries (CEEC). It is a catalyst for research, innovation, and rural development, and it assists in the development of bioeconomy-related policies in the CEEC. Energy Institute Hrvoje Požar as a partner in this consortium works closely with the Ministry of Agriculture on the establishment of Taskforce for Bioeconomy Strategy development.

Within the framework of the Instrument for Pre-Accession Assistance (IPA) - Operational Program for Regional Competitiveness, HAMAG-BICRO, in cooperation with the Ministry of Science, Education and Sports, University of Zagreb and the City of Zagreb, prepared the project "Incubation Center for Bio- science and commercialisation of technology - BIOCenter ". The BIOCentre is conceived as an active factor in ensuring productive relationships between basic and applied scientific research and the economy, technological infrastructure and new biotechnology companies in the process of developing new products. The planned infrastructure consists of business and laboratory facilities for the needs of small, high-tech enterprises and a central laboratory designed to develop the production process for bio-products, in accordance with Good Manufacturing Practice (GMP) including:

- Bank of stations
- Cell Growing Laboratory
- Microbiology laboratory
- Product Insulation Unit
- Laboratory for purification
- Bio-analytical laboratory
- Substrate and Buffer Preparation Unit
- Bio-test preparation unit

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7.3. Educational infrastructure

The educational system in the Republic of Croatia is divided into preschool education, elementary education, secondary education and higher education. Preschool education in the Republic of Croatia encompasses education and care of the children of preschool age, realised through educational, health care, nourishment and social care programs for children from six months of age until school age. Elementary education in the Republic of Croatia lasts for eight years and it is compulsory and free for all children between the ages of six and fifteen (this refers to all children with permanent residence in the Republic of Croatia, irrespective of their citizenship). There are around 860 elementary schools on the territory of the Republic of Croatia.

7.3.1. Secondary education

Secondary education is implemented through a network of more than 700 secondary schools that are divided according to the program they offer as follows:

1. Gymnasiums (general or specialised) – offer a program that lasts at least four years
2. Vocational or trade schools (technical, industrial, trade and others) – offer a program that lasts from one to five years, and programs of from one to two years
3. Art schools (music, dance, visual arts and others) – offer a program of at least four years

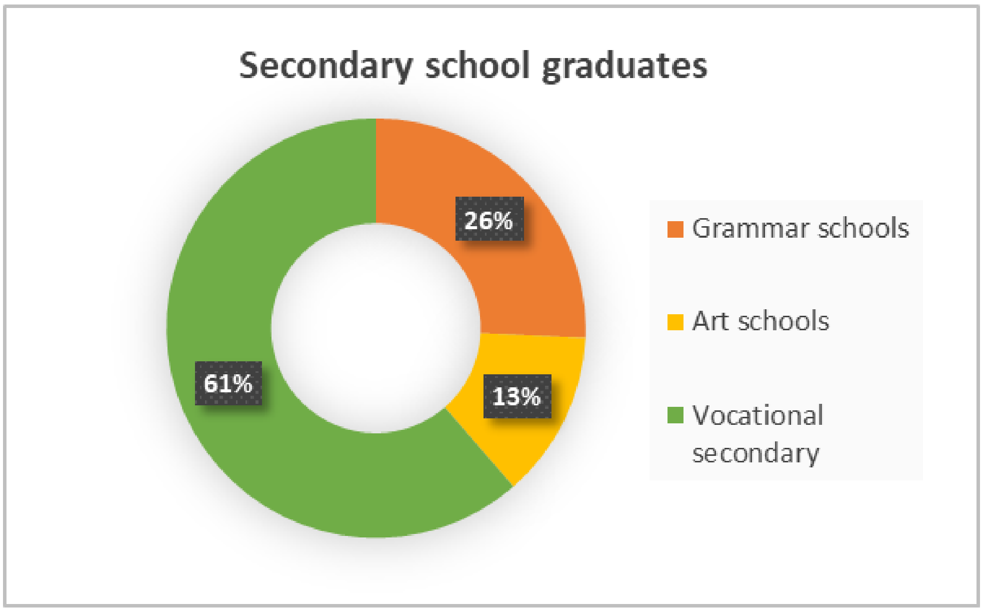

Figure 38 Secondary school graduates

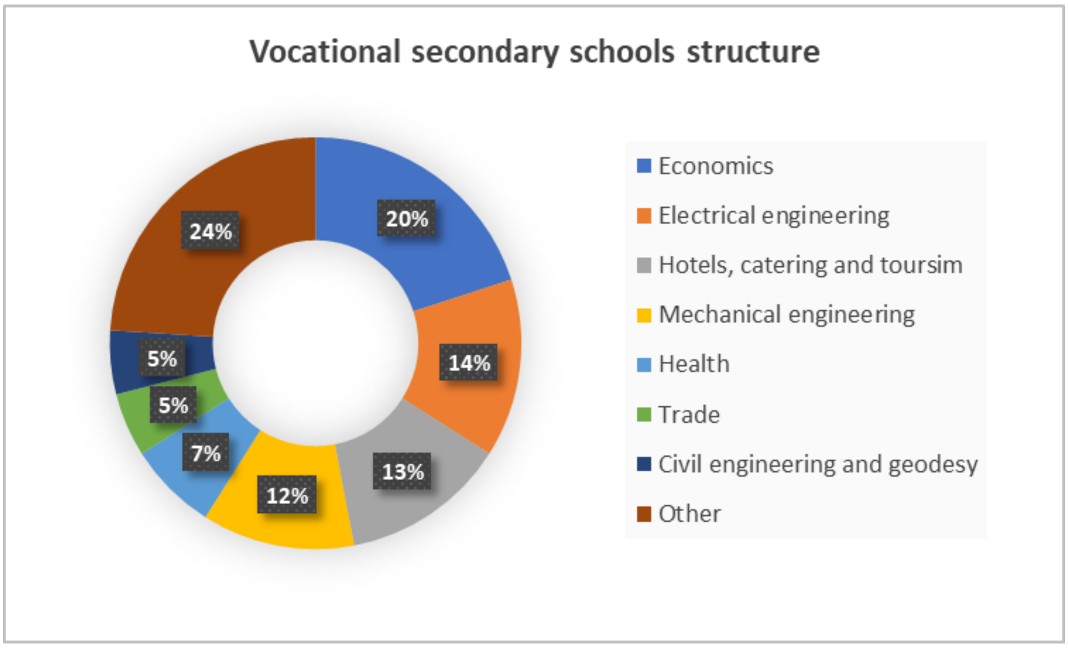

Figure 39 Detailed analysis of graduates in Vocational secondary schools

7.3.2. Higher education

Croatia has three types of higher education institutions: universities, polytechnics and colleges of applied sciences. The Croatian education system is harmonised with the EU education system (Bologna). There are currently 132 higher education institutions in Croatia.

The Croatian higher education system comprises of 8 public universities, two private universities, 11 public polytechnics, four private polytechnics, three public colleges and 22 private colleges.

Faculty of Agriculture, University of Zagreb has adopted a new Master's Degree programme "Renewable Energy in Agriculture". The program aims to provide, through the modern teaching process, the education of students in the field of agricultural sciences and the interaction of agriculture and energy and the sustainable use of biomass, biofuels and waste in agriculture. The aim is, therefore, to equip students to deal with the environmental problems associated with agricultural production and the use of farming resources for the production of renewable energy, as well as the management of various types of waste. Some of the courses are: Biomass and Biofuels, Waste management in agriculture, Energy crops, Bio-based products from lignocellulosic biomass etc.

The graduate study programme INTER-EnAgro offers theoretical and practical knowledge targeted at sustainable use and management of natural resources such as soil and water as well as positive and negative effects of human activities, primarily agriculture, on these resources. It is based on the contemporary teaching process and entirely English taught study programme (with the participation of national and international teachers). The objective is to educate experts who will have the knowledge, skills and competencies in the fundamental and applied scientific fields of agriculture, environmental protection and related natural, engineering and biotechnical sciences. Some of the courses are: Agroclimatology and climate change, Environmental risk analysis and management, Water management in agriculture etc.

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7.4. Environment for start-ups

The development of start-up entrepreneurship (start-up culture) is one of the essential factors in creating competitive advantages of the national economy. The largest Entrepreneurship Institution in the Republic of Croatia is the Ministry of Entrepreneurship and Crafts, followed by the **Croatian Agency for Small Business, Innovation and Investments - HAMAG-BICRO**, Croatian Chamber of Economy (HGK), Croatian Chamber of Trades and Crafts (HOK), Croatian Employers Association (HUP), **Croatian Bank for Reconstruction and Development (HBOR)** and the Croatian Employment Service (CES), through their programs and incentives, help and encourage entrepreneurs to develop their ideas and start their own businesses. Entrepreneurial support institutions are (Nikolić and Zorić, 2014):

- Regional development agencies
- Entrepreneurial centres
- Entrepreneurial incubators (more and more involved are student entrepreneurs' incubators)
- Technology parks
- Entrepreneurial education institutions
- Entrepreneurial accelerators

The newly established **EIT Climate KIC Hub** in **Croatia** is a consortium of eight organisations that are different in structure and mandate, but complementary in their missions and activities. These are the Zagreb Innovation Centre, the Regional Energy Agency of Northwestern Croatia, the Technology Transfer Office of the University of Zagreb, Geotechnical Faculty, University of Zagreb, Terra Hub, the Green Energy Cooperative, the Knowledge Network and the Impact Hub Zagreb. The consortium aims to promote and establish an economy that is aware of all the effects and challenges of climate change, responsibly acting and working on innovative solutions, operating and building systemic changes in an ecosystem that includes all sectors and levels of society.

CIRTT cooperates with the Croatian Agency for Small Business, Innovation and Investments - HAMAG-BICRO in the implementation of the Proof of Concept (**PoC**). PoC provides funding to demonstrate technical feasibility, prototype and protect intellectual property, and market analysis and commercialisation planning. The goal of PoC is to facilitate the journey from scientific research results to solutions ready for commercialisation. From 2010 to 2015, five PoC calls were concluded and with the support of CIRTT, a total of 46 projects of around HRK 9.5 million in innovation development were implemented. In 2016 23 projects were implemented with a total value of HRK 6.9 million.

Oradian is a Croatian startup that has developed a global microfinance platform, and with Oradian software which is a system for supporting financial institutions in micro-lending, they surpass American startups Prove and Japanese Storygami.

Croatian cloud livestock monitoring platform, or "**Google Farm Analytics**" Osijek-based Farmeron, in 2014, secured a new round of financing of $ 2.65 million. In practice, it is about keeping track of how much a cow has given milk through integration with technical equipment, as well as a calendar that reminds the client of all the obligations crucial for healthy livestock.

Agrivi' s vision to change the way food is produced in its core and positively impact one billion lives by helping farmers reach sustainable, resource-efficient and profitable production. Agrivi has aggregated the best farming practices for over 100 crops and put them on a dashboard so farmers can make data-driven decisions at all points in the growing season. In 2014 Agrivi won the World Startup Competition in Seoul and now helps thousands of farmers from more than 130 countries, in their native languages. The startup was founded in 2013 and has raised a total of $ 1.4 million from South Central Ventures.

7.5. Public-private partnerships

Regarding public investments, Government of the Republic of Croatia established Centre for Monitoring Business Activities in the Energy Sector and Investments (CEI), intending to find solutions for improving the financial effectiveness of companies in the energy sector in which the state has shares or holds stock, and appropriate and targeted directing of funds in a manner ensuring biggest and most long-term economic return, stable growth and centralised and systematic monitoring of all investments in the Republic of Croatia. The total capital value of over EUR 2 billion.

The Republic of Croatia made a significant improvement of the legislative framework giving assurance to the investors when entering PPP projects, which contributes to the overall attractiveness of Croatian investments in public infrastructure projects. In April 2012, the Government of the Republic of Croatia adopted a Framework Program for the Construction, Upgrading and Reconstruction of Public Buildings under the Contract Form of Public-Private Partnership (PPP), with a total capital value of over € 2 billion.

Ongoing private-public partnerships in Croatia:

- **Justice Square in Zagreb**
- **Neuropsychiatric Hospital "Dr. Ivan Barbot" Popovaca**
- **Istria County & Town of Poreč - Schools**
- **Varazdin County - Schools**
- **General Hospital Varaždin**
- **Koprivnica - Schools**

Croatia is open to all potential investors having an interest in investing in the projects in Croatia, whether they are private or public.

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O.n.	Name of PPP project	CAPEX (excluding VAT)*	DYNAMICS OF PROJECT IMPLEMENTATION (COMPLETED ACTIVITIES AND EXPECTED DATES)					
			INFORMATION ON THE INTENT OF THE IMPLEMENTATION OF THE PROJECT	PROJECT SUBMITTED TO THE PPP AGENCY FOR APPROVAL PROPOSAL (INCL. PSC, CONTRACT DOCUMENTATION)	APPROVAL OF PPP AGENCY	PUBLIC PROCUREMENT	CONTRACTING	START OF USING - AVAILABILITY PAYMENT OF THE PUBLIC PARTNER
1	JUSTICE SQUARE - ZAGREB	1.350.000 HRK 177.632 EUR	FINISHED	PERFORMED	APPROVED	FINISHED (1st LVL OF COMPETETIVE DIALOGUE, WAITING FOR THE DECISION OF DUUDI TO CONTINUE THE PROJECT)	8 MONTHS UPON THE BEGINNING OF THE 2ND LVL OF COMPETITIVE DIALOGUE	5 YEARS FROM BEGINNING OF CONSTRUCTION
2	NEUROPSYCHIATRIC HOSPITAL "Dr. Ivan Barbot" POPOVAČA	124.500 HRK 16.382 EUR	FINISHED	PERFORMED	APPROVED	IN PROGRESS	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2 YEARS FROM CONSTRUCTION COMMENCEMENT
3	GENERAL HOSPITAL VARAŽDIN	370.000 HRK 48.684 EUR	FINISHED	PERFORMED	APPROVED	IN PROGRESS	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2,5 YEARS FROM CONSTRUCTION COMMENCEMENT
4	CROATIAN HISTORY MUSEUM	137.000 HRK 18.026 EUR	FINISHED	PERFORMED PSC, CONTRACT IN PROGRESS	TO BE DEFINED	TO BE DEFINED	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2 YEARS FROM CONSTRUCTION COMMENCEMENT
5	VARAŽDIN COUNTY SCHOOLS (4 schools)	107.000 HRK 14.079 EUR	FINISHED	PERFORMED	APPROVED	IN PROGRESS	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2 YEARS FROM CONSTRUCTION COMMENCEMENT
6	ISTRIA COUNTY & TOWN OF POREČ SCHOOLS (4 schools)	145.760 HRK 19.179 EUR	FINISHED	PERFORMED	APPROVED	IN PROGRESS	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2 YEARS FROM CONSTRUCTION COMMENCEMENT
7	TOWN OF KOPRIVNICA SCHOOLS (3 schools)	100.000 HRK 13.158 EUR	FINISHED	PERFORMED	APPROVED	IN PROGRESS	UP TO 3 MONTHS UPON SELECTION OF PRIVATE PARTNER AND FINANCIAL CLOSE	2 YEARS FROM CONSTRUCTION COMMENCEMENT
8	BJELOVAR COUNTY SCHOOLS (11 schools)	120.000 HRK 15.789 EUR	TO BE DEFINED	IN PROGRESS	TO BE DEFINED	TO BE DEFINED	TO BE DEFINED	TO BE DEFINED
9	CLINICAL HOSPITAL CENTER RIJEKA	3.900.000 HRK 513.158 EUR	FINISHED	TO BE DEFINED	TO BE DEFINED	TO BE DEFINED	TO BE DEFINED	TO BE DEFINED
	TOTAL	6.494.120 HRK 854.489 EUR				* in 000 HRK/EUR 1 EUR = 7,60 HRK		
	PPP PROJECTS IN STRUCTURING							
1	CITY OF ZAGREB SCHOOLS (6 schools)	OTHER INFORMATIONS WILL BE AVAILABLE UPON PROJECT STRUCTURATION						
2	TOWN OF ŠIBENIK SCHOOLS (2 SCHOOLS)							
3	KOPRIVNICA KRIŽEVCI COUNTY SCHOOLS (7 schools)							

Figure 40 List of PPP in Croatia

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7.6. Summary and conclusions in relation to SWOT elements

Croatia is in the near future threatened by the outflow of skilled labour, which in turn has a negative impact on economic performance and the economic situation in general. The relationship between the labour market and skilled labour force indicates a slow adaptation of the education system to new business trends and required skills.

In terms of higher education, Croatia inherits a long tradition of participation of its universities at the global level. Strong foothold in research community plays a crucial role in setting a milestone for bioeconomy development. There is a need for the research community to expand their work into applied research to create a pathway for bioeconomy stakeholder development. The lack of cooperation between the private sector and academia is evident and needs more encouragement on the government level. While there is existing infrastructure within BIOCentar and it could be used as a tool for strengthening these relations, this option has not yet taken effect. Start-up culture in Croatia is gaining momentum, but slow administration and outdated regulations make it difficult to move forward. At this moment, start-up companies are reduced to an individual approach. In terms of PPP, the broadening of the framework programme is necessary.

Table 33 SWOT analysis of educational, innovation and skills sector in Croatia

Strengths	**Weaknesses**
Strong academic community High potential for knowledge transfer (quality schools, universities) Laboratory equipment at universities On-topic ongoing research projects Start-up entrepreneurship Proof of Concept programme	The insufficient connection between academia, public and the private sector A lack of applied research A small rate of medium TRL (3–6) research/development infrastructure The loss of experts (scientists, engineers, doctors, …) due to "brain drain" No PPP in other sectors, except construction Lack of individual approach at academia level
Opportunities	**Threats**
Pilot projects to connect the academy community, public and private investors PPP expanding to other sectors Programmes to keep the young people in the country (decrease "brain drain")	The loss of experts (and young people) due to rising competitiveness and better work conditions in other countries The loss of start-up companies due to lack of recognition of the legislative framework

8. Policy framework: Regulations, legislation, rule of law & taxes and tariffs

8.1. Introduction

Croatia does not have a strategy for fostering bioeconomy. However, there are regulations, strategic goals and priorities that are encompassed in the different national strategies i.e. Smart Specialization Strategy and Action Plan (S3), Rural Development Programme, Energy Development Strategy of the Republic of Croatia By 2030, with a view of 2050. It directs the use of funds in the context of the Operational Programme for the execution of the European cohesion policy for the 2014-2020 period. The S3 also applies to other funds and instruments of the developmental policy. Several other frameworks serve as a general support for bioeconomy in Croatia, and they include funding from the EU, as well as from the Ministries.

8.1.1. Smart specialisation strategy 2016-2020.

S3 presents a comprehensive assessment of the country's governance structure, innovation facilitating instruments, and key innovation assets –research and human capital. It proposes a strong monitoring and evaluation (M&E) framework and provides a sectoral analysis of five priority sectors of the economy and their innovation potential. The main purpose of Smart Specialization is to transform the Croatian economy and increase its competitiveness by concentrating knowledge resources and linking them to a limited number of priorities. The identification of the Smart Specialization priorities will allow the concentration of research capacities and infrastructure. It will provide an advantage to both the public and private sector and will bring together the critical mass of researchers who will jointly work on strategic R&D topics with the goal of research excellence and its commercialisation. The Croatian S3 embraces product, process, service, marketing and organisational innovations in line with the definitions laid out in the Oslo Manual: (1) product innovations - market introduction of a new or significantly improved good or service with respect to its capabilities, user-friendliness, components or sub-systems; (2) process innovations - implementation of a new or significantly improved production process, distribution method, or supporting activity; (3) marketing innovations - significant changes to design, packaging, product promotion, placement, and pricing; (4) organisational innovations - new or improved business practices for organising procedures, work responsibilities and decision making, service delivery, and external relations.

8.1.2. Industrial Strategy of the Republic of Croatia 2014.-2020.

The main objective of Croatian industry has been defined by this strategy, and it states the following: repositioning of identified strategic activities in the global value chain towards the development of activities that create added value. Alongside the main goal, several other goals have been defined, and they are the following:

1. Increase in industrial production at an average annual rate of 2.85%
2. Increase in the number of new employees by 85,619 by the end of 2020., of which at least 30% are highly educated
3. Increase in labour productivity by 68.9% between 2014.-2020.
4. The increase in export between 2014.-2020. by 30% and transformation of export structure in favour of export products with high added value

8.1.3. CAP: Croatian Rural Development Programmes 2014-2020

The European Common Agricultural Policy (CAP) provides a framework for financial support to farmers (Pillar 1 - Direct Payments), and national rural development programmes (Pillar 2 - Rural Development). The new CAP 2014-2020 has been presented in 2014, and the Member States has adapted their national approach within this framework. In 2015 the new Croatian CAP came into force.

The Rural Development Program of the Republic of Croatia for the period 2014-2020, by analysing the context (SWOT analysis) and conducted assessment, defines the priorities and areas of intervention, the selection of relevant measures and the allocation of funding based on expected outcomes. One of the goals of the Program is resource efficiency and climate change resilience in agriculture, food processing and forestry, emphasizing that renewable energy production from these sectors is a priority for developing the bioeconomy and reducing greenhouse gases by 2020. Furthermore, the importance of the use of wood biomass, biomass from agriculture and solar energy in agriculture and the food processing industry is emphasized.

The program defines 18 measures aimed at increasing the competitiveness of Croatian agriculture, forestry and the processing industry, as well as improving living and working conditions in rural areas in general.

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8.2. Summary and conclusions in relation to SWOT elements

Ministry of Agriculture took the lead in the development of Bioeconomy Strategy and Action Plan which are expected to be adopted by spring 2021. At this moment, bioeconomy is not the central topic of any specific Croatian framework or policy. There are, however, several national and EU frameworks that touch on the topic of bioeconomy: Smart Specialization Strategy (S3) (it focuses on economy and increase its competitiveness by concentrating knowledge resources and linking them to a limited number of priorities), Industrial Strategy (emphasises the opportunities Croatia has identified as strategic activities in the global value chain towards the development of businesses that create added value) and the Rural Development Program (mentions the conventional use of agricultural and forest biomass, as well as energy production).

However, in order to develop the legal framework, all stakeholders from the bioeconomy sector need to be included and contribute to the creation of a quality strategy: Ministry of energy and environmental protection, Ministry of infrastructure, Ministry of education, etc.

Table 34 SWOT analysis of the Croatian policy framework

Strengths	**Weaknesses**
Raising awareness of bioeconomy potential for strengthening the agricultural sector and economy in general Thematic Innovation Council for food and bioeconomy within S3 Development phase of National Energy and Climate Action Plan for 2021-2030 CAP post-2020 BIOEAST initiative	Slow policy-making framework Most measures rely on voluntary pledges from the private sector A lack of a circular agricultural policy A lack of financial incentive/subsidies to foster bioeconomy development
Opportunities	**Threats**
Establishment of Committee for the development of Bioeconomy Strategy Policies for improved biomass managing, increase in the use of residues Strong agri-food sector Stimulation of the use of recognised certificates Removing exhaustive administrative regulationsProgrammes to keep the young people in the country (decrease “brain drain”)	Ignoring the rising awareness of the need for structural change in policy Continuous relying on voluntary pledges from companies

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9. Financing

9.1. Introduction

Business activities in Croatia can be financed either through standard loans of commercial banks or institutions offering more favourable interest rates or issuing guarantees for bank credits. Consisting of 25 banks, 1 saving bank and 5 building societies, a traditionally stable and highly developed sector, the Croatian banking system offers high diversification and good quality of financial products and services.

An important role in helping companies in their further developing and exporting activities has the Croatian Bank for Reconstruction and Development (HBOR). Through its specialized programs HBOR provides support to start-ups, exporting companies, new production and companies from different sectors of economy such as industry, tourism, environmental protection and energy efficiency, agriculture, etc. More information about HBOR programs can be found on its web site *www.hbor.hr*. Additional support to business activities is provided by the Government Agency for SMEs, Innovations and Investments (HAMAG-BICRO). HAMAG-BICRO issues guarantees for bank credits approved by credit institutions and other legal entities approving loans to SMEs and makes direct financial contributions to SMEs in a form of grants. More information about HAMAG-BICRO guarantees and grant schemes can be found on its web site www.hamagbicro.hr. There is an additional financing option for entrepreneurs and investors in developing their projects in Croatia, and that are EU funds. As 28th full member state of the European Union, the Republic of Croatia has possibility of using the assets from the Structural Funds and Cohesion Fund. The total budget of Croatia for the financial period 2014-2020 is EUR 12,653,688,161.00, which includes the Cohesion Fund (CF), the European Social Fund (ESF), the European Regional Development Fund (ERDF), the European Agricultural Fund for Rural Development (EAFRD), the European Maritime and Fisheries Fund (EMFF) and the Youth Employment Initiative (YEI)[23].

[23] https://pjr.hr/koliko-su-eu-fondovi-iskoristeni-u-hr/

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As of 2018, Croatia contracted 68% of the estimated amount (selection decisions), while payments to end users were 17%[24]. For individual funds the amounts are as follows:

Table 35 Utilization of European funds in Croatia as of 31.12.2017.

	Selection decisions (contracted)	Payments (to end-users)
Cohesion Fund (CF)	43%	4%
European Regional Development Fund (ERDF)	28%	18%
European Maritime and Fisheries Fund (EMFF)	31%	11%
European Regional Development Fund (ERDF)	50%	8%
European Social Fund (ESF)	21%	3%
Youth Employment Initiative (YEI)	46%	17%

Table 36 Bioeconomy funding programmes

Bioeconomy funding programmes	
X	Bio-based industrial sector
X	Bioeconomy R&I
V	Infrastructure investments - BIOCenter
V	Other×
× Croatian Science Foundation provides support to scientific, higher education and technological programmes and projects, fosters international cooperation, and helps the realization of scientific programmes of special interest in the field of fundamental, applied and developmental research.	

24 https://razvoj.gov.hr/UserDocsImages/Istaknute%20teme/MRRFEU%20rezultati%202018..pdf

9.2. Summary and conclusions in relation to SWOT elements

Croatia has a high potential for fostering bioeconomy, but the realisation of this potential ultimately depends on the financing. There are different possible funding schemes, but the most significant problems are slowness of the system and unrealistic goals. EU funding provides resources for research and innovation and SME's competitiveness. HAMAG-BICRO recently increased visibility of financial lines towards family farms, SME's and entrepreneurs in the tourism sector which resulted in rising of new applications and development of new business activity in these sectors. HBOR has introduced a new line of business financing for young entrepreneurs, women and beginners. Therefore, monetary funds are available, but the barrier of slow and inefficient bureaucracy needs to be bridged.

Table 37 SWOT analysis of the Croatian financing sector

Strengths	**Weaknesses**
EU funds Financial lines available to entrepreneurs Areas of excellence in academia and industrial research	Low investment activity in processing activities in the direction of transitioning to bio-based alternatives Insufficient supporting activity of financial institutions towards bioeconomy projects (e.g. venture capital funds) Poor knowledge of public procurement procedures Low level of trust in public institutions
Opportunities	**Threats**
Enhance State or Government funding and subsidies for fostering bioeconomy Better use of available EU funding in the field of bioeconomy Regional resource connecting (RDI, production, logistics)	Rising competitiveness of bio-based industries in neighbouring countries Reduced government funding and use of EU funds Possible risky nature of investment A lack of agencies providing equity and loans for bio-based initiatives

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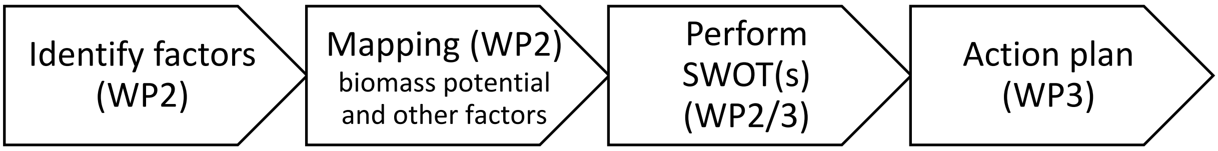
Approach guiding the structure and contents of this report

Identification of factors that are important for establishing bio-based production chains in a country

One of the objectives of the CELEBio project is to map opportunities in the target countries for setting up bio-based business activities. This includes the mapping of the biomass feedstock potentials, and other key success factors for establishing bio-based production chains, e.g. business activities, what bio-based products can be generated, and what is the market demand of these products.

The BBI is focused on the next bio-based products and markets: Chemicals, Plastics (polymers, materials, packaging), Specialties (surfactants, lubricants, pharmaceuticals, nutraceuticals, cosmetics), Textiles, Food ingredients and feed, Advanced biofuels.

To be able to perform SWOT(s) and generate action plans, the first step is to identify which factors are important. These factors should be determined based on the perspective of both entrepreneurs/business developers and governments. The identified factors should be mapped and will be the basis for performing a SWOT (Strength, Weakness, Opportunity and Threat) analysis for development of bio-based production chains.



Based on input from industry and business developers a logical set of factors was identified that guide the choice of investing in the bio-based economy and location of conversion plants (Van Dam et al., 2014). This set is expanded/updated (amongst others based on the BBI project BIOFOREVER (bioforever.org)). Via an interview sheet, different stakeholders (15) from different countries (the Netherlands, Croatia, Czech Republic, Hungary, and Slovenia) were asked to comment on the factors and rank them.

Highest ranked factors:

- Feedstock supply: price, security of supply, quality
- Product market: price, off-take security
- Regulations, legislation, and rule of law

Medium raked factors:

- Financing: investors, subsidies, guarantees, risk minimization options
- Taxes and Tariffs
- By-product valorisation: heat, CO2, fodder, lignin

Lowest ranked factors:

- Infrastructure: what part of the chain is already available (harbour, industries)
- Logistics: cost, reliable
- Technology: TRL, robustness, yield, CAPEX, OPEX
- Sustainability: economical, environmental, and social aspects

Overall, the ranking of the factors only differed slightly. Most of the experts mentioned that all the identified factors are important and that a system approach is key in developing bio-based initiatives. If one link in the chain is missing, the bio-based initiative will not succeed.

According the experts the most important stakeholders for establishing bio-based production chains are:

- Producers/suppliers of biomass
- Chemical industry
- Energy industry
- R&D organizations
- Regulatory authority
- Environmental organizations
- Public

Annex 1 Explanation of the S2BIOM approach to assessing lignocellulosic biomass potentials from agriculture, forestry and waste

In S2BIOM project the core biomass cost supply data was generated in WP1 for 37 European countries at regional level. Lignocellulosic biomass assessed by S2BIOM includes biomass originating from the following:

- Primary residues from agriculture
- Dedicated cropping of lignocellulos biomass on agricultural area
- Wood production and primary residues from forests
- Other land use
- Secondary residues from wood industry
- Secondary residues of industry utilising agricultural products
- Waste collection/ tertiary residues

To consult and download biomass cost-supply data from the S2BIOM toolbox see: https://s2biom.wenr.wur.nl/web/guest/biomass-supply#_48_INSTANCE_nYA0VqOhoRGM_%3Dhttps%253A%252F%252Fs2biom.wenr.wur.nl%252Fbiomasscostsupplyviewer%252Findex.html%253Fclassic%2526

Data have been assessed for 2012, 2020 and 2030. They are provided for several 'potentials' including: a technical potential; a base potential considering currently applied sustainability practises; and further potential levels that are determined considering changing sustainability restrictions, mobilisation measures and different constraints to account for competing use.

The technical potential represents the absolute maximum amount of lignocellulosic biomass potentially available for energy use assuming the absolute minimum of technical constraints and the absolute minimum constraints by competing uses. This potential is provided to illustrate the maximum that would be available without consideration of sustainability constraints.

The base potential can be defined as the technical potential considering agreed sustainability standards for agricultural forestry and land management. The base potential is thus considered as the sustainable technical potential, considering agreed sustainability standards in CAP (Common Agricultural Policy) for agricultural farming practices and land management and in agreed (national and regional) forestry management plans for forests (equivalent to current potentials described in EFSOS II). This also includes the consideration of legal restrictions such as restrictions from management plans in protected areas and sustainability restrictions from current legislation. Further restrictions resulting from RED (Renewable Energy Directive) and CAP are considered as restrictions in the base potential as well. CAP sustainable agricultural farming practices include applying conservation of Soil Organic Carbon (SOC) (e.g. Cross Compliance issues of 'maintaining agricultural land in good farming and management condition' and avoiding soil erosion).

The user-defined potentials vary in terms of type and number of considerations per biomass type. Following the general nomenclature of potentials, the user defined potentials can also be considered as sustainable technical potentials but differ in the constraints considered vs the base potential and among each other. The user can choose the type of biomass and the considerations he would like to employ and calculate the respective potential accordingly. This flexibility is meant to help the user to understand the effect on the total biomass potential of one type of consideration against the other. These can include both increased potentials (e.g. because of enhanced biomass production) or more strongly constrained potentials (e.g. because of selection of stricter sustainability constraints).

Technical, base and one user defined (UD) potential has been assessed for all biomass groups. For forest biomass many more user defined potentials were quantified. See underneath:

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Table 38 Overview of agricultural residual biomass potential types and considerations

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobilisation
Technical (straw & stubbles)	Area in 2012, 2020, 2030 with cereals, rice, sunflower, rape, corn maize	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030	Maximum volume of straw and stubbles that could be harvested in 2012, 2020 and 2030	None	None
Technical (prunings permanent crops)	Area in 2012, 2020, 2030 with fruit trees, vineyards, olive & citrus	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030	Maximum volume of prunings and cuttings that could be harvested in 2012, 2020 and 2030	None	None
Technical (sugarbeet leaves & tops)	Area in 2012, 2020, 2030 with sugar beet	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030	Maximum volume of sugarbeet leaves and tops that could be harvested in 2012, 2020 and 2030	None	None
Base (straw & stubbles)	As for technical potential	As for technical potential	Only the biomass part can be removed that is not needed to keep the SOC stable. This is assessed according to carbon content that is removed with the residue and the SOC level in the soil that has to be maintained.	None	None
Base (prunings permanent crops)	As for technical potential	As for technical potential		None	None
Base (sugar beet leaves & tops)	As for technical potential	As for technical potential	Removal of leaves and tops from field is only allowed in Nitrate vulnerable zones where nitrogen surplus needs to be declined through removal of nitrogen rich biomass.	None	None
User potential (straw & stubbles)	As for technical potential	As for technical potential	As in base	In cereal straw a subtraction is applied according to demand for straw for animal bedding & feed . For rice straw, corn stover and sunflower and rape stubbles no competing uses are assumed.	None
User potential (prunings & cuttings)	As for technical potential	As for technical potential	All pruned material is available that is currently according to real practices NOT used to maintain the SOC and fertility of the soil. So the part	None	The potential that is NOT used for SOC and fertility maintenance according to current practices needs to be mobilised gradually

			that is now removed to the side of the field for energy uses or that is burned with & without energy recovery is seen as potential and can be removed. This follows the common treatment practices of prunings as assessed in the EUROpruning project.		as it requires a change in management. It is therefore assumed; it becomes available from 50% in 2012 to 60% in 2020 and 70% in 2030.

Table 39 Overview of woody biomass potential types used in S2BIOM

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobilisation
Technical	Forest area available for wood supply. This excludes protected and protective areas, where harvesting is not allowed according to protection purpose.	Growth based on regional to national growing conditions, including changes in biomass increment due to climate change. Yield according to regional management guidelines for age limits for thinnings and final fellings.	Maximum volume of stemwood that could be harvested annually during 50-year periods. Technical constraints on residue and stump extraction (recovery rate)	None	None
High	As for technical potential	As for technical potential	As for technical potential, but considering additional less stringent constraints (compared with base potential) for residue and stump extraction: Site productivity -Soil and water protection: ruggedness, soil depth, soil surface texture, soil compaction risk -Biodiversity (protected forest areas) -Soil bearing capacity.	None	None
Base	As for technical potential	As for technical potential	As for technical potential, but considering additional constraints for residue and stump extraction: -Site productivity -Soil and water protection: ruggedness, soil depth, soil surface texture, soil compaction risk -Biodiversity (protected forest areas)	None	None

			-Soil bearing capacity.		
User potential - option 1	Reduction of FAWS by 5%	As for technical potential	Equivalent increase of protected forest area by 5%.	None	None
User potential - option 2	Reduction of FAWS by 5%	As for technical potential	Increase of protected forest area by 5% and increase in retained trees by 5%.	None	Reduction in harvest by 5%
User potential - option 3	As for technical potential	As for technical potential	No stump extraction.	None	None
User potential - option 4	Reduction of FAWS by 5%	As for technical potential	Increase in protected forest by 5% plus increase in retained trees by 5% plus no stump extraction	None	Reduction in potentials by 5%
User potential - option 5	As for base potential	As for base potential	As for base potential	Roundwood production for material use (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Pulpwood, Round & Split + Other Industrial Roundwood) in period 2010-2014) subtracted from BP.	None
User potential - option 6	As for base potential	As for base potential	As for base potential	Roundwood production for material use excl. for pulp and paper and board industry (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Other Industrial Roundwood) in period 2010-2014) subtracted from UP4.	None
User potential - option 7	As for user potential - option 4	As for user potential - option 4	As for user potential - option 4	Roundwood production for material use (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Pulpwood, Round & Split + Other Industrial Roundwood) in period 2010-2014 subtracted from BP.	As for user potential - option 4
User potential - option 8	As for user potential - option 4	As for user potential - option 4	As for user potential - option 4	Roundwood production for material use excl. for pulp and paper and board industry (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Other Industrial Roundwood in period 2010-2014) subtracted from UP4.	As for user potential - option 4

Table 40 Overview of potentials calcultated for biowaste and wood waste

Technical potential The Technical potential represents the amount of biomass assuming only technical constraints and a minimum of constraints by competing uses. In case of biowaste no constraints are considered in the technical potential. In case of post-consumer wood, the technical potential assumes that 5% of all wood waste cannot be recovered and used for energy application for technical reasons. Competing uses (current material application of the wood) are not taken into account.
Base potential This is the sustainable technical potential, considering currently agreed sustainability standards. In case of biowaste the base potential equals the technical potential. In case of post-consumer wood, the base potential takes into account the current material application of recovered wood, and assumes that this material application remains constant in 2020 and 2030
User defined potential The user-defined potentials vary in terms of type and number of considerations per biomass type. The user can choose the type of biomass and the considerations he would like to add and calculate the respective potential. This flexibility is meant to help the user to understand the effect on the total biomass potential of one type of consideration against the other. In case of biowaste no user-defined potentials have been developed. In case of post-consumer wood, one user-defined potential has been developed. This user defined potential on cascading use of post-consumer wood takes into account the current material application of post-consumer wood in 2012, and assumes that the material application of non-hazardous post-consumer wood will increase to 49.2% in 2020 and 61.5% in 2030, or remain stable if current (2012) material use is higher.

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Primary agricultural residual biomass assessments

For the assessment in S2BIOM (like for Biomass Policies) land-use and livestock production levels are used based on the most recent CAPRI baseline run 2008-2050, providing intermediate results for 2010, 2020, 2030 and 2050.

The potential supply of agricultural residues was estimated for the period from 2012, 2020 and 2030. It uses as main input the cultivated land and main crop production and yield combinations made for these years by the CAPRI model. Residual biomass covered in S2BIOM from agriculture comes from primary residues from arable crops (straw and stubbles) and pruning, cutting and harvesting residues from permanent crops.

The assessment of residues from arable crops builds on methodologies and assessments already done in Biomass Policies and Bioboost. The assessment for vineyards, olive groves and fruit plantation residues bases build on work done in EuroPruning project.

The aim of S2BIOM was to identify the part of the residues that can be removed from the field without adversely affecting the SOC content in the soil.

It is the carbon balance module in the MITERRA-Europe that has been further adapted in S2BIOM (and Biomass Policies) to take account of removal of straw (and also prunings, see next). This was done by incorporating the RothC model (Coleman and Jenkinson, 1999) into MITERRA-Europe. RothC (version 26.3) is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (tonne C ha-1), microbial biomass carbon (tonne C ha-1) and Δ14C (from which the radiocarbon age of the soil can be calculated) on a years to centuries timescale (Coleman and Jenkinson, 1999). For this study RothC was only used to calculate the current SOC balance based on the current carbon inputs to assess taking account of soil types (including Soil C levels) the sustainable crop residue removal rates at which the carbon C in the soil remains constant.

Primary forest biomass potential assessment

The potential supply of woody biomass was estimated for the period from 2012 to 2030 for stemwood; branches and harvest losses (further: ‘logging residues’); and stumps and coarse roots (further: ‘stumps’) (Table 20). First, we estimated the theoretical potential of forest biomass supply in Europe based on detailed forest inventory data. This theoretical potential was defined as the overall, maximum amount of forest biomass that could be harvested annually within fundamental bio-physical limits (adapted from Vis and Dees 2011, Dees et al. 2012), taking into account increment, the age-structure and stocking level of the forests. Second, multiple environmental and technical constraints were defined and quantified that reduce the amount of biomass that can be extracted from forests for different biomass potential types. Third, the theoretical potentials from the first step were combined with the constraints for the biomass potential types.

This sequence of steps is based on the approach developed and applied within the EUwood and EFSOS II studies (Verkerk et al. 2011; UNECE et al. 2011; Verkerk 2015). The approach in S2BIOM differs from previous studies in several ways, with the main difference being that that woody biomass potentials have been estimated using a typology of

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potentials developed within S2BIOM. Other changes include (i) an updated of the forest inventory data used as a basis to estimate biomass potentials; (ii) extension of the geographical scope to include all 37 S2Biom countries; (iii) improvements to set the of constraints; and (iv) improve the potential estimates at regional level by spatially disaggregating estimated biomass potentials. All improvements are described below.

The large-scale European Forest Information SCENario model was applied (EFISCEN) (Sallnäs, 1990) to assess the theoretical potential of forest biomass at regional to national level. Versions 3.1.3 (Schelhaas et al. 2007) and 4.1 (Verkerk et al. 2016a) were used because the former version is included in a script to estimated biomass potentials Verkerk et al. (2011), while the latter version has the ability to directly store results in a database, which is used to run the EFISCEN disaggregation tool (Verkerk et al. 2016b). EFISCEN describes the state of the forest as an area distribution over age- and volume-classes in matrices, based on data on the forest area available for wood supply (FAWS), average growing stock and net annual increment collected from NFIs. Forest development is determined by different natural processes (e.g. increment) and is influenced by human actions (e.g. management). A detailed model description is given by Schelhaas et al. (2007; 2016).

National forest inventory data on area, growing stock and net annual increment are used to initialize the EFISCEN model.

The amount of wood that can be felled in a time-step is controlled by a basic management regime that defines the period during which thinnings can take place and a minimum age for final harvest. Age-limits for thinnings and final fellings were based on conventional forest management according to handbooks at regional to national level (Nabuurs et al. 2007) and by consulting national correspondents (UNECE-FAO 2011). The amount of stemwood potential removed as logs was estimated by subtracting harvest losses from the stemwood felling potential. Harvest losses were estimated using the ratio between fellings and removals as reported by UNECE-FAO (2000) for coniferous and broadleaved species separately.

Branches together with harvest losses represent logging residues that can be potentially extracted as well. In addition, stumps could potentially be extracted, separately from logging residues. The volume of branches, stumps and coarse roots was estimated from stemwood volume (incl. harvest losses) using age-dependent, species-specific biomass distribution functions (Vilén et al., 2005; Romano et al., 2009; Mokany et al., 2006; Anderl et al. 2009). We assumed no difference in basic wood density between stems and other tree compartments, due to lack of information.

Climate change is accounted using results from LPJmL (Sitch et al. 2003, Bondeau et al. 2007). Data are an average for several climate models for the A1b SRES scenario. Annual tree Net Primary Production (NPP) in gC/m2 for 3 individual years (2010, 2020, 2030) was calculated with LPJmL and used to scale the increment functions used in EFISCEN.

Secondary biomass potentials from agro-food industry

For an overview of the calculation methods and assumptions of secondary biomass sources from agro-food industries see Table 4.

Table 41 Overview of assessment rules applied in S2BIOM to assess potentials for olive stones, rice husk, pressed grapes residues and cereal bran

Biomass type	Area / Source	Residue factor	Technical & environmental constraints
Olive-stones	CAPRI & national statistics: Area with all olive trees (table=oil olives) 2012, 2020, 2030	Olive pits make up between 10%-12.5% of the weight of olive according to Garcia et al. (2012) and Pattarra et al., (2010)	**Base=** pits from all oil olives + 30% of table olives
Rice husk	CAPRI & national statistics: Area with rice in Europe 2012, 2020, 2030	Rice husk is approximately 20% of the processed rice, with average moisture content of 10% ((Nikolaou, 2002)). It is assumed that all rice produced in the S2BIOM countries is locally processed	None
Pressed grapes residues (pressing residues & stalks)	CAPRI & national statistics: Area with vineyards in Europe 2012, 2020, 2030	Of the processed grapes 4.6% consists of dregs and 1.5% of stalks (*FABbiogas (2015)- Italian country report*)	None
Cereal bran	CAPRI total estimate of tonnes processed cereals per EU country	In wheat processing 20% to 25% wheat offals (Kent et al., 1994). Wheat bran represents roughly 50% of wheat offals and about 10 to 19% of the kernel, depending on the variety and milling process (WMC, 2008; Prikhodko et al., 2009; Hassan et al., 2008). . So the residue to yield factor used is 10% of cereals processed domestically.	None

For the calculation of the olive stones, rice husk and pressed grapes dregs we assumed that all domestic production would also be processed locally and that is no further processing of imported olives, rice and grapes. This implied that the residues would be available locally and that the regional distribution of the processing residues is a direct outcome of the cropping area distribution over regions in every country.

For cereal bran it is more logical to assume that the basis should be the total amount of cereals processed in every country. This implies that cereal bran needs to be calculated for a total net domestic cereal production and imports:

$$\textit{Domestic production}_{cereals} - \textit{export}_{cereals} + \textit{import}_{cereals}$$

The data on total domestic production, exports and imports levels were available from CAPRI for 2010 (extrapolated to 2012), 2020 and 2030 for all S2BIOM countries except for Ukraine.

To come to a regional distribution of the cereal bran potentials in every S2BIOM country 2 assumptions were made:

1) The bran based on the net domestic production (=domestic production – exports) is distributed regionally according to cereal production area share.
2) The cereal bran based on processing of imported biomass is distributed over largest (port) cities per country as it is expected that processing industries are there where imports enter the country and where population is concentrated. The residues were spatially distributed to regions with the large and medium sized cities (>100,000 inh.), every city was equally weighted.

Method used to estimate secondary forest biomass produced in the forest processing industry

The EU-Wood study (Mantau, 2010) projects the demand for material use without considering competition with other sectors in order to explore if the increasing demand for energy will lead to a strong competitive situation where the demand substantially exceeds the supply. The EU-Wood project (Mantau, 2010) has aligned the prediction of the future demand to the real GDP (Gross domestic product) and thus the prediction that utilises the IPCC B2 scenario assumptions shows a strong increase (see Figure 41**Error! Reference source not found.**).

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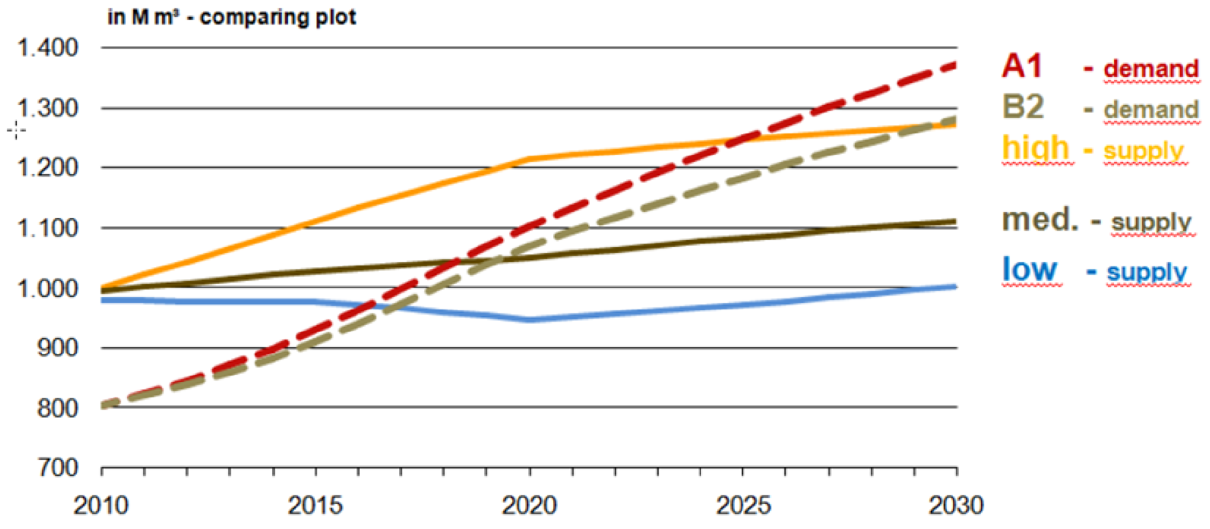

Figure 41 Future development of demand and supply as projected by the EU-Wood project for different scenarios (Mantau, 2010)

Thus, to constrain the potentials by such demand projection would constrain the potential with strong preference to material use. The recent trends of the forest products consumption index indicate that the production has changed its relation to the GDP (Figure 42).

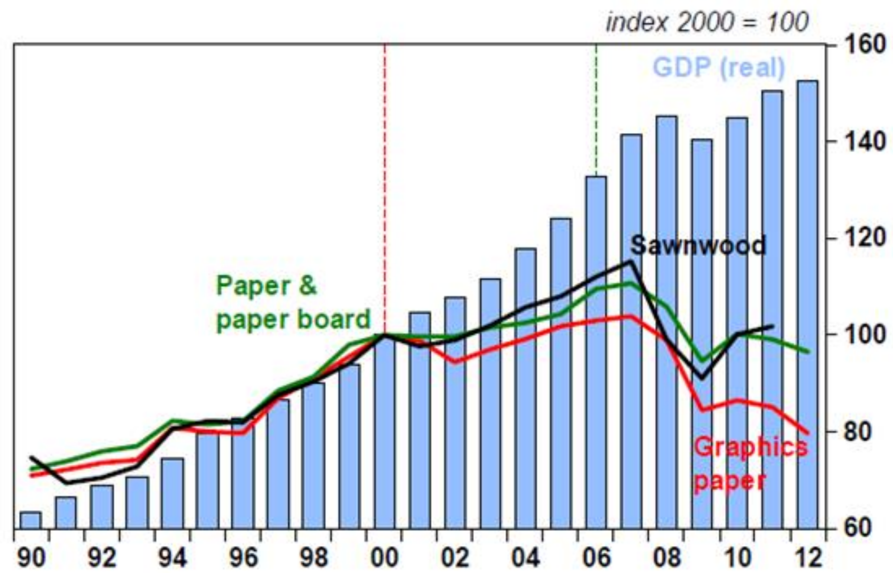

Figure 2.1.2. EU GDP (real) and forest products consumption index over the period 1990-2012 (2000 = 100). (Forest products data from FAO; GDP data from IMF, Gross domestic product based on purchasing-power-parity (PPP) valuation of country GDP).

Figure 42 EU GDP and forest products consumption index[25]

[25] Source: Birger Solberg, Lauri Hetemäki, A. Maarit I. Kallio, Alexander Moiseyev and Hanne K. Sjølie (2015) Impacts of forest bioenergy and policies on the forest sector markets in Europe – what do we know?

An alternative to use predicts the future industry production results from modelling that considers economic competition. Such estimates are available from the EFSOS II study for 2010, 2020 and 2030. The trends of the EFSOS II study are utilised by S2BIOM. Figures 3 and 4 show for sawn wood and panels that the S2BIOM data for 2012 are close to EFSOS II reference scenario projections 2010.

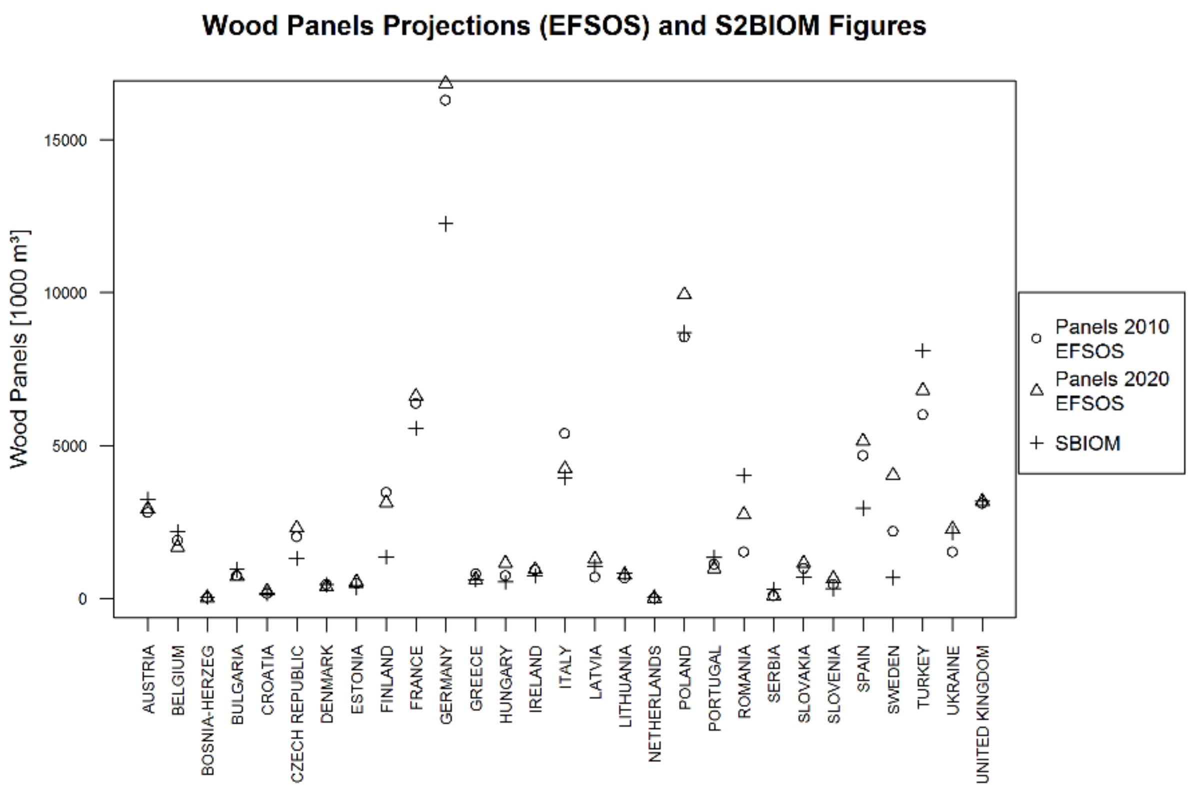

Figure 43 Wood panel production, EFSOS 2 reference scenario projections, and S2BIOM 2012 estimates

The S2BIOM residue and production figures of the timber industry were thus projected to the years 2020 and 2030 using the growth rates of the reference scenario of the UNECE European Forest Sector Outlook Study II (EFSOS II) for sawnwood and wood-based panel production.

For the pulp and paper sector there was a huge difference between S2BIOM 2012 quantities and the EFOS reference scenario projections.

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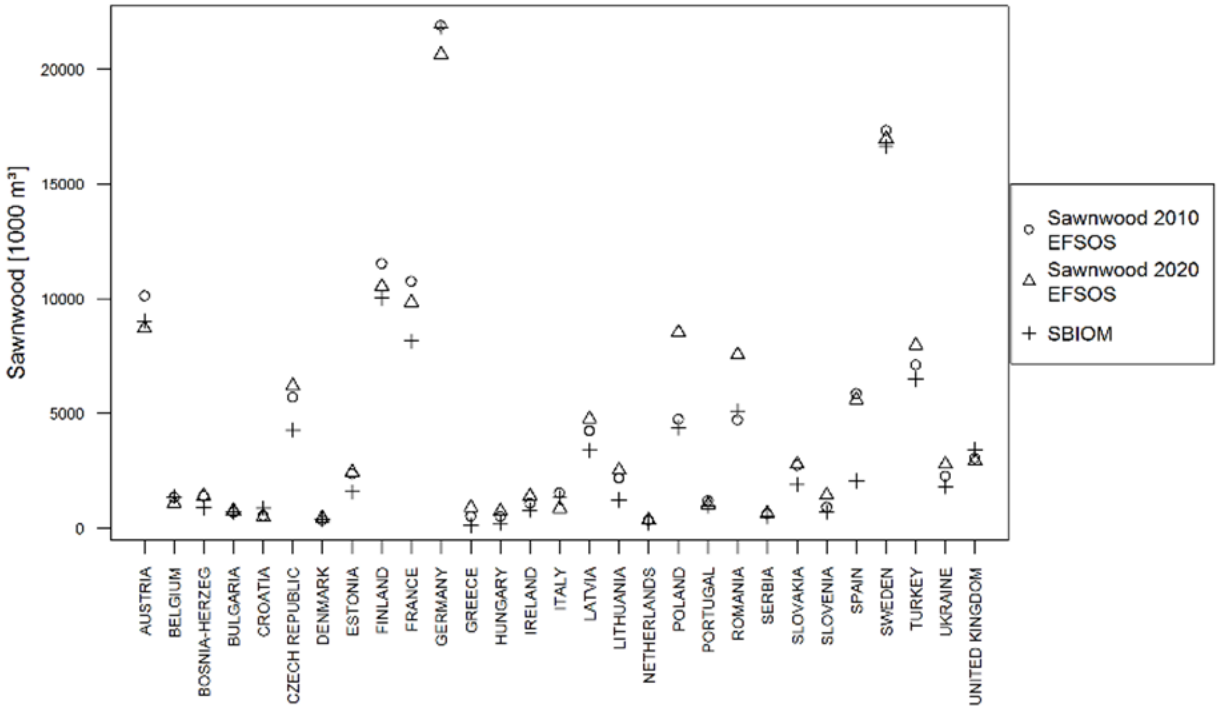

Figure 44 Sawnwood production, EFSOS 2 reference scenario projections and S2BIOM 2012 estimates

The visualisation of the figures from the "Historic Statistics" report of CEPI on pulp and paper production are shown in Figure 5. This figure shows the changes of pulp production for the CEPI member states which are: Austria, France, Netherlands, Romania, Sweden, Belgium, Germany, Norway, Slovak Republic United Kingdom, Czech Republic, Hungary, Poland, Slovenia, Finland, Italy, Portugal and Spain. It is for S2BIOM assumed that the changes in production after some bigger fluctuations in the past will be in 2020 and 2030 in the same dimension as in 2012. Hence the production quantities from 2012 are used for 2020 and 2030 as well.

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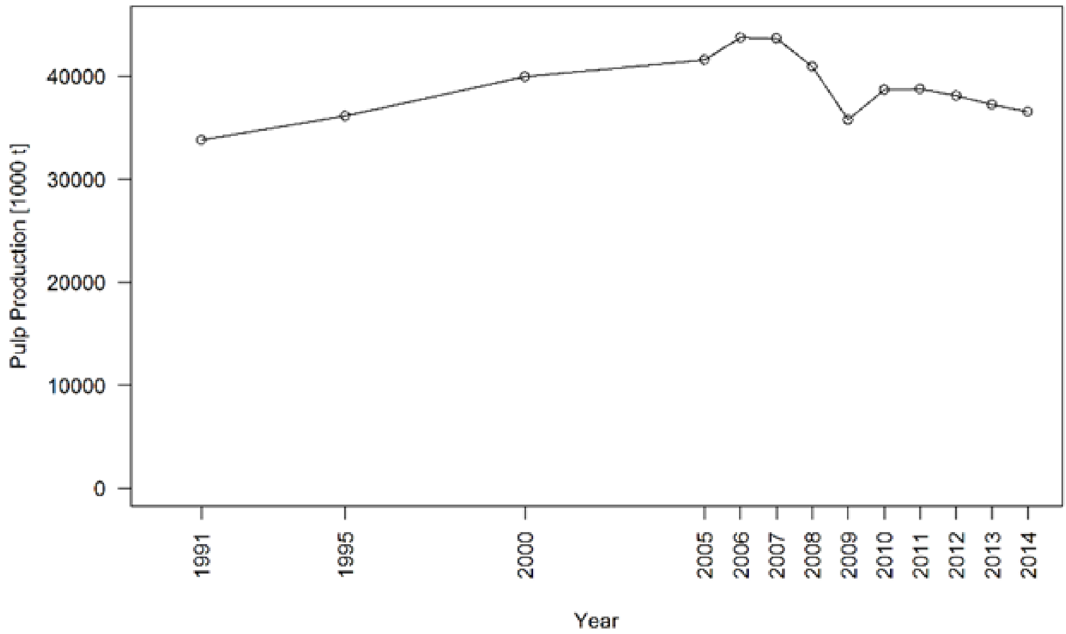

Figure 45 Development of Pulp production, CEPI data

The approach used is summarised by category in Table 42.

Table 42 Approach used to estimate future production amount in the wood industry

Sector	Approach
Saw mill residues, conifers	EFSOS II sawnwood, reference scenario
Saw mill residues, non-conifers	
Residues from industries producing semi - finished wood based panels	EFSOS II wood based panels production, reference scenario
Residues from further wood processing	EFSOS II sawnwood, reference scenario
Secondary residues from pulp and paper industry	Kept constant

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Assessment of biowaste and post-consumer wood potentials

The availability of biowaste in 2012 on NUTS3 level was established as:

MSW generated per capita (kg/capita) x

biowaste fraction (%) x

population of the NUTS3 area (persons).

A further distinction has been made between the separately collected biowaste and biowaste as part of mixed waste. In Arcadis and Eunomia (2010) projections have been provided of the shares of biowaste going to the different treatment options like landfill, incineration, MBT, composting, backyard composting, anaerobic digestion and others have been made for the years 2008-2020. It has been assumed that all countries meet the requirement of the landfill directive, e.g. that maximally 35% of the amount of biodegradable waste generated in base year 1995 is landfilled in 2020, even if current developments show that diversion from landfill has not been successful yet. Furthermore, the projections are based on policy views and current changes in treatment of biowaste in the member state concerned. For instance, some countries have a strong preference for MBT, others for incineration with energy recovery. For the year 2030 the same shares between treatment options are used as in the year 2020. Currently no policies are known that influence the production of biowaste after 2030, therefore it is assumed that the projected status quo in 2020 will be maintained in 2030.

Projections on the development of the total quantity of biowaste are assumed to be proportional to population growth. The main scenario on population development from Eurostat has been used to predict the population in 2020.

The calculation of the post-consumer wood potential is calculated according to the following formula:

$$PCW_{\text{technical potential}} = PCW_{\text{material}} + PCW_{\text{energy}} + PCW_{\text{disposed}}$$

$$PCW_{\text{base potential}} = PCW_{\text{energy}} + PCW_{\text{disposed}}$$

in which:

$PCW_{\text{recovered}}$ = PCW used for materials like panels and chipboards

PCW_{energy} = PCW used for energy production

PCW_{disposed} = landfilled and/or incinerated with MSW.

Eurostat gives data on “wood waste”, but this includes not only post-consumer wood but processing wastes from agriculture forestry and fishing sectors. Because of this mixture of secondary wood processing and tertiary post-consumer wood within one category, Eurostat data could not be used to determine the potential of post-consumer wood. For S2BIOM, data on recovered wood were used from a forest biomass resource assessment done for the

EUwood and EFSOS II studies (Mantau et al. 2010; UN-ECE/FAO 2011[26]). EUwood combines among others Eurostat and COST Action E31 data. The EFSOS II data on demolition wood is based on EU wood but covers Europe as a whole instead of EU28. In order to determine the base potential PCW available for energy, it is necessary to estimate how much is used for material applications. In the Methodology report of the EUwood project[27], a table is given on the availability of *PCW recovered* [for material recycling] and *PCW energy* for 2007, page 119-120, which have been used in S2BIOM as well.

Assessment of cost levels for different biomass categories in S2BIOM

Because we are still in the early stages of a transition of fossil-based feedstock towards bio-based feedstock there is hardly any information of enough quality to conduct a meaningful market analysis. In this light it is important to keep in mind that a distinction needs to be made between different types of cost and price levels specific per biomass type:

- Market prices exist for already traded biomass types (e.g. straw, wood chips and pellets based on primary and secondary forestry residues).
- Road-side-cost for biomass for which markets are (practically) not developed yet (e.g. many agricultural and forestry residues, dedicated crops for ligno-cellulosic and woody biomass and waste streams such as vegetal waste). These may cover the following cost:
  - (Production cost (in case of dedicated crops, not for residues or waste)
  - (Pre-treatment in field/forest (chipping, baling)
  - (Collection up to roadside/farm gate
- At-gate-cost which cover the cost at roadside plus transport and pre-treatment cost of biomass until the biomass reaches the conversion plant gate (e.g. bioethanol plant, power plant).

The cost assessed in S2BIOM are limited to the **road-side cost**. So, the cost from roadside for transport and possible in-between treatment to the gate of the conversion installation or the pre-treatment installation are NOT included.

Cost assessment for agricultural biomass potentials

The overall methodology followed to gain insight in the minimum costs of production is the *Activity Based Costing* (ABC). It involves the whole production process of alternative production routes that can be divided in logical organisational units, i.e. activities. The general purpose of this model is to provide minimum cost prices for the primary production of biomass feedstock at the roadside. ABC generates the costs of different components based on specific input and output associated with the choice of the means of production, varying with the local conditions and cost of inputs (e.g. labour, energy, fertilisers, lubricants etc.). Since the production of most biomass is spread over several years, often long-term cycles in which cost are incurred continuously while harvest only takes place once in so many years, the Net Present Values (NPV) of the future costs are calculated. This provides for compensating for the time

[26] UNECE (United Nations Economic Commission for Europe), FAO (Food and Agricultural Organization of the United Nations) 2011: The European Forest Sector Outlook Study II; Geneva
[27] EU Wood (2010) Methodology report, real potential for changes in growth and use of EU forests EUwood. Call for tenders No. TREN/D2/491-2008.

preference of money. To account for the fact that the costs are declining in different periods of time in the future the Net Present Value annuity is applied. In this way annual, perennial crops and forest biomass cost are made comparable (=all expressed in present Euros).

The cost is automatically calculated for all field operations per year in a 60-year cycle in the case of agricultural biomass. The cost of wood production was not considered in this study as these costs need to be allocated to the main product, while here the focus is on the cost of the residues. Cost are presented as NPV per annum and expressed in € per tonne dm or per GJ.

It is also important to note that the costs calculated in here are at the farm level cost. We are aware that the costs for the next link in the value chain might be higher because of rent seeking behaviour. However, in this approach we did not take account of it as we did not include a profit margin.

As explained in the former cost of agricultural biomass are calculated for *Net Present Value annuity* taking a 60-year coverage period. These 60 years are chosen to fit all possible cycles in the cost calculation as 60 is fully synchronizable to 1,3,5,10,15,20,30 and 60 years cycles. Cost differences after that period are negligible. In this way, cost for biomass from residues and from dedicated crops can be assessed with the same model and can be made comparable.

First the Net Present Values of all activities are calculated as follows:

Formula:

$$\mathbf{NPv=Fv/(1+i)^n}$$

Where:

NPv = Net Present value

Fv = Future value

i = the interest rate used for discounting (set to 4%)

n = number of years to discount

Then the Net Present Value annuity is applied, assuming that the sum of NPVs cover the annual capital payments attracted against the same interest rate (4%) as the discount rate used for calculating the NPVs.

Formula:

$$\mathbf{NPVa=\Sigma NPv*(1/((1-(1+i)^{-n})/i))}$$

Where:

NPVa = Net Present Value annuity

ΣNPv = sum of NPVs

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n = number of years

i = the interest rate (set to 4%)

The cost also allows for national differentiation of cost according to main inputs having national specific prices levels. The is organised through the **'Country inputs'** module in the ABC model. It contains detailed information concerning the prices of various resources needed as input for the production process of biomass specific per country. These are specified, either in absolute price levels or as an index related to the known price level in one or two specific countries (mostly Germany). This is necessary as prices of key production factors differ a lot at national level across Europe. National level price data (ex. VAT) included cover cost/prices for labour (skilled, unskilled and average), fuel, electricity, fertilizers (N, P2O5, K2), machinery, water, crop protection and land. Most of these data were gathered from statistical sources such as FADN (Farm Accountancy Data Network), Eurostat and OECD. Most cost levels were gathered for the year 2012.

The cost data elaboration also requires a feedstock specific approach. If cost are estimated for biomass that is specifically produced for energy or bio-based products, i.e. in the case of dedicated crops the cost structure is clear and all cost can be allocated to the final product. All cost should include the fixed and variable cost of producing the biomass including land, machinery, seeds, input costs and on field harvesting costs. If the biomass is a waste, i.e. cuttings of landscape elements or grass from roadside verges, the cost could be zero, as cutting and removing these cutting is part of normal management. However, bringing the biomass to the conversion installation requires some pre-treatment costs, e.g. for drying or densifying and then transport costs have to be made to bring it to the conversion installation. These costs will not be assessed here however as we concentrate on the roadside cost.

Crop residues also require a separate approach as harvesting cost can usually be allocated to the main products, i.e. grain in the case of cereal straw, and not to the residue. However, the baling of the straw and the collection up to the roadside can be included in the costs.

For the elaboration of cost levels account also needs to be taken of the local circumstances and type of systems used for the production and harvesting of the biomass. This is particularly complex in the case of dedicated crops for which cost estimates are mostly and/or only available from pilot plots and practically no commercial plantations. Costs vary strongly per type of management, soil and climate zone. Furthermore, cost need to be allocated per tonne harvested mass over the whole lifetime of a plantation as harvest levels are very low in the first years and increase in time.

The cost is determined for 2012, the reference year and are kept constant in the future years 2020 and 2030. The reason for keeping cost constant in time has several advantages:

1) Estimations of future changes in prices for (fossil) energy (fuel & electricity), labour, and machinery are difficult to predict. If predictions are used this implies automatically adding additional uncertainties in the cost assessment.

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2) If cost levels do not alter in time the uses of the cost-supply data in other models in and outside S2BIOM (e.g. Resolve and BeWhere) deliver results that can only be explained from the internal logic of the models and not by differences in cost level increases based on a large number of uncertainties.
3) The cost levels presented in S2BIOM can still be further adapted by other users applying their own assumptions on future cost level changes. This enables them to use the S2BIOM cost-supply data consistently with their own modelling assumptions.

Cost assessment for forest biomass

The estimation of harvesting and comminution costs is following the approach presented earlier by Ranta (2002, 2005), Ilavský et al. (2007), Anttila et al. (2011) and Laitila et al. (2015). In contrast to the cost estimates for energy crops, the production costs are not considered in the cost estimates.

The data are mostly determined by the S2Biom project. A survey of cost factors related to forest harvesting operations was carried out in cooperation with INFRES project (Dees et al. 2015).

The methodology can be divided into two main components: 1) the estimation of hourly machine costs, and 2) the estimation of productivity. All the cost estimations pertain to current cost level (year 2012).

The general workflow is illustrated in Figure 46.

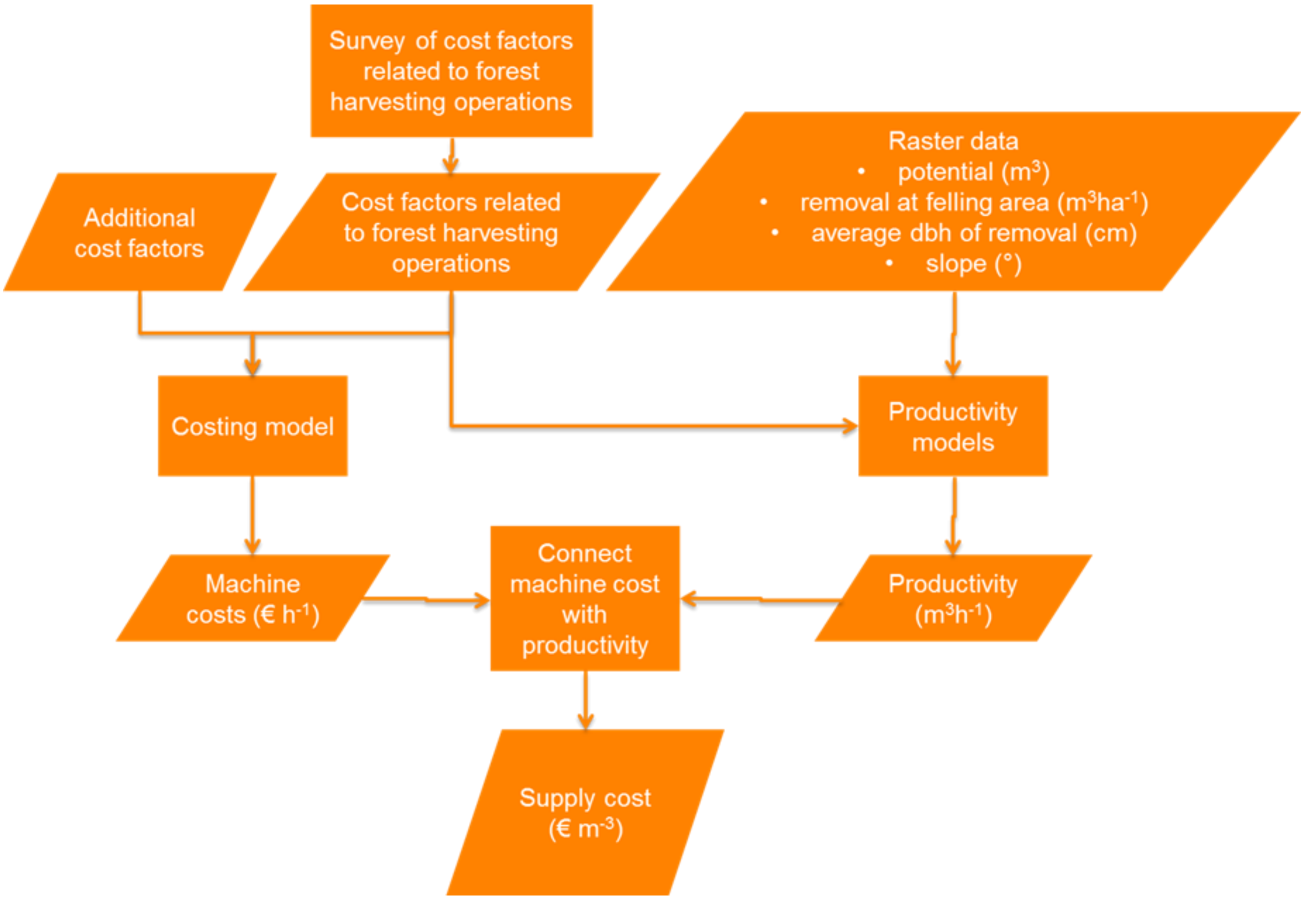

Figure 46 General workflow of the forest biomass cost calculations

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Cost estimates for biowaste and post-consumer wood

This study follows the activity-based costing approach. In principle, the costs of harvesting collection and forwarding to the roadside need to be considered. The cost to put the biowaste in a container at roadside is assumed to be zero. The cost of further collection and processing is covered by the households and organisations that need to discard the biowaste, regardless its possible further application for energy production. Waste collection and treatment is part of the public tasks and the cost for it cannot be allocated to the processor of the waste. In case of biowaste we could define the municipal collection point as “at roadside”. From this municipal collection point, the municipality can select which waste treatment option is preferred, within the framework of European and national policy, considering costs and sustainability of the treatment methods.

The cost of discarding post-consumer wood in a container at roadside is regarded zero. For instance, demolition activities are performed to make space for another building, and not with the purpose to generate wood waste. Demolition activities will follow legal instruction, i.e. put waste wood fractions in separate containers if this is required by law. For other sources of post-consumer wood such as packaging materials or household waste a similar approach can be applied. Packaging waste is of no value to organisations. Consumers bring wooden furniture to a central collection point, or put it at roadside for pick-up, not the sake of providing energy wood. Once collected and sorted, waste wood fractions have an economic value, which can be considerable if there is sufficient demand. However, as said, S2BIOM follows an activity based costing approach, considering the costs, not the economic value of the material. The roadside cost of demolition wood is therefore assumed zero.