Chapter 19
Agricultural Biomass Ash as a Circular Building Material: Connecting Agriculture and Construction Industry

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Abstract Previous studies have indicated that agricultural biomass ash is an important resource with great potential for the construction sector. To valorize agricultural waste (as a renewable energy source and as a supplementary cementitious material—SCM), the crucial steps in the integrated management system of the circular economy cycle are the establishment and maintenance of database on crop production, namely, on harvest residues amount and quantity and quality of available biomass ash. The purpose of the study was to establish a multi-level georeferenced interactive database (map) on the produced quantities of agricultural biomass ash and cement consumption in Vojvodina region (Republic of Serbia), based on the analysis of agricultural biomass ash stream through three sectors as potential actors of the supply chain: agriculture (biomass producers)—industry (biomass users)—construction industry (users of biomass ash). Conducted research indicates the annual potential of over 2.4 million tons of harvest residues from corn, wheat, soya and sunflower, available for energy purposes in Vojvodina region. The potentially available amount of ash that might be generated annually by harvest residues combustion is estimated at over 196 thousand tons. Identified available amount of biomass ash (4.2 thousand tons) indicates an extremely low utilization (~2%) of the biomass potential. On an annual basis, all current agricultural biomass ash production can be used for partial cement substitution up to 30% in six construction companies. However, the generated ash is mostly disposed of in municipal landfills, which represents the end of the waste stream.

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L. Bragança et al. (eds.), *Creating a Roadmap Towards Circularity in the Built Environment*, Springer Tracts in Civil Engineering,
https://doi.org/10.1007/978-3-031-45980-1_19

Keywords Agriculture · Industry · Construction industry · Biomass ash · Waste management · Circular building materials

19.1 Introduction

Agriculture and the construction industry are essential sectors for a country's economic growth [1]. However, both sectors are large consumers of natural resources and generate significant amounts of wastes and green-house gases, that negatively affect human health, ecosystems and the economy.

One of the main problems in agriculture is an inadequate management of waste, as agricultural activities generate huge volumes of biomass residues. It is estimated that globally 140 Gt of agricultural residues are generated each year [2]. In recent years agricultural biomass has gained a global value as an alternative fuel for energy production, being considered as a renewable and CO_2-neutral energy resource. Despite the increasing consumption of biomass as an energy source, enormous quantities remain unused in landfills or burned by households.

The processing and disposal of the ash resulting from biomass combustion has become another environmental and economic issue. Biomass ash is the solid residue produced during the incineration of biomass for heat and electricity production and represents ~2–20% of the input material [3]. The available literature reflects the current situation in which energy production from biomass is the primary intention and ash utilization is often neglected [4]. Biomass ash is a relatively consistent potential resource for manufactured products, but still recycling and recovery rates of these wastes remain low and much is landfilled, or "downcycled" and used as lower-value materials [5].

The largest emitter of greenhouse gases is the construction sector, reaching nearly 38% of global CO_2 emissions, mainly from the production of cement, that reached a 4.3Gt in 2021 [6, 7]. The sector needs to reduce these emissions by embracing the principles of a circular economy.

The inclusion of biomass ash into cement-based materials, valorised as a SCM, which has been investigated in various studies [8], is a promising circular economic strategy to reduce the CO_2 emissions and minimize waste through its utilization.

The Republic of Serbia belongs to the countries that have significant biomass potential, estimated at 3.448 Mtoe per year. In the total potential of renewable energy sources, biomass participates with 61%. The largest part of this potential is agricultural biomass potential (48%) and wood biomass potential (44%) [9]. Agricultural biomass refers to the harvest residues, pruning residues and livestock manure, while the most significant source of agricultural biomass is represented by harvest residues. Regardless of the amount of agricultural biomass that is generated on an annual basis, the utilization rate is not higher than 2% [9].

The research was conducted for the region of the Autonomous Province of Vojvodina where the majority of agricultural biomass available at the territory of the Republic of Serbia is located [9]. Vojvodina is situated in the northern part of the

Republic of Serbia, in the Pannonian Basin in Central Europe. It covers an area of 21.506 km^2 and is divided into 7 districts, with a population of 1.75 million people [10].

To valorize agricultural waste (as a renewable energy source and as a SCM), the crucial steps in the integrated management system of the circular economy cycle are the establishment and maintenance of database on crop production, namely, on harvest residues amount and quantity and quality of available biomass ash. The purpose of the study was to establish a multi-level georeferenced interactive database (map) on the produced quantities of agricultural biomass ash and cement consumption in Vojvodina region, based on the analysis of agricultural biomass ash stream through three sectors as potential actors of the supply chain: agriculture (biomass producers)—industry (biomass users)—construction industry (users of biomass ash). The area of interest covered 4 districts of Vojvodina: North Bačka, West Bačka, South Bačka and Srem.

19.2 Analysis of Agricultural Biomass Ash Stream in Vojvodina Region—Methods

The analysis of agricultural biomass ash stream was conducted through three phases that included:

1. assessment of agricultural biomass potential for ash production,
2. assessment of the availability of biomass ash and
3. assessment of the capacities for the production of cement composites based on agricultural biomass ash.

Collected geospatial data on the produced quantities of biomass ash and cement consumption were integrated into a common database, within the free open-source geographic information system program—QGIS, which enabled the establishment of multi-level georeferenced interactive map.

19.2.1 Agricultural Biomass Potential for Ash Production

The assessment of agricultural biomass potential for ash production included:

- collection of data on agricultural crop production;
- calculation of the amount of residues that remain on the fields after harvest;
- calculation of the amount of harvest residues available for energy use;
- calculation of potentially available amount of ash generated by biomass combustion;
- analysis of collected data and obtained results.

As a system for monitoring the agricultural biomass potential in the Republic of Serbia does not exist, the assessment is based on the production of major harvested crops, whose harvest residues can be used as an energy source in the industry, replacing traditionally used fossil fuels. Data on crop production for a period of 5 years (2017–2021) were collected from national statistical yearbooks. In order to calculate the quantity of residues that remains on the fields after harvest, the average value of the annual quantity of individual crops for the observed time period was determined and multiplied by the coefficients indicating the quantitative ratio of basic crop product and biomass.

Quantities of harvest residues available for energy use are calculated as 30% of the total amount of crop residues, in accordance with the estimation that 30% of the produced above-ground biomass can be collected from the field without reducing the humus content of the soil [11].

As the amount of ash generated by the combustion process is not usually measured, the potentially available amount of ash that could be generated by the combustion of corn stalks, corn cobs, wheat straw and sunflower stalks and heads is estimated at approximately 8% and in the case of sunflower husks at a maximum of 5% of the calculated amount of harvest residues available for energy use [12]. The assessment of the potential for ash production was carried out through the analysis of crop production stability, the amount of ash that theoretically can be generated by biomass combustion and usability in terms of biomass collection possibilities in the fields.

19.2.2 Availability of Agricultural Biomass Ash

The assessment of the availability of biomass ash included the analysis of available data on companies that use harvest residues for energy purposes [13]. Data on used biomass types, generated quantities of biomass ash per year and ash disposal were analyzed.

19.2.3 Capacity for the Production of Cement Composites Based on Agricultural Biomass Ash

The assessment of the capacities for the production of mortar and precast concrete elements, where cement partially can be substituted with agricultural biomass ash, is based on the analysis of available data on construction companies. The assessment included:

- collection of data on average annual concrete production;
- calculation of total annual consumption of cement for concrete production;
- calculation of potential average annual consumption of biomass ash for cement substitution (cement savings);

- comparative analysis of available biomass ash and its potential consumption.

Based on the average annual production of concrete, the total annual consumption of cement was determined. The assumed average amount of cement in 1 m^3 of concrete, for the production of prefabricated elements, is 350 kg [14]. Depending on the percentage of cement substitution (10–50%), potential average annual biomass ash consumption was calculated and compared with available biomass ash, identified in phase two.

19.3 Results and Discussion

19.3.1 Agricultural Biomass Potential for Ash Production

With 83% Vojvodina has a noticeably high share of arable land in relation to the total land area and a low share of forest area (7%) [15], which implies that the region in general has significant agricultural biomass potential. The greatest potential for energy utilization lies in harvest residues, which make up 58% of the total biomass [15].

Total quantities of major harvested crops whose harvest residues can be used as an energy source in the industry for the period 2017–2021 [16, 17] are presented in Fig. 19.1.

In the structure of analyzed agricultural crops, cereals have the largest share—corn 59.1% and wheat 24.2%, while the share of industrial crops is significantly lower—sunflower 8.5% and soya 8.2%. The lowest crop production was recorded in 2017. In 2018 crop production increased by 57% and this continuity of production was maintained during 2019 and 2020, with minor deviations. Compared to 2020,

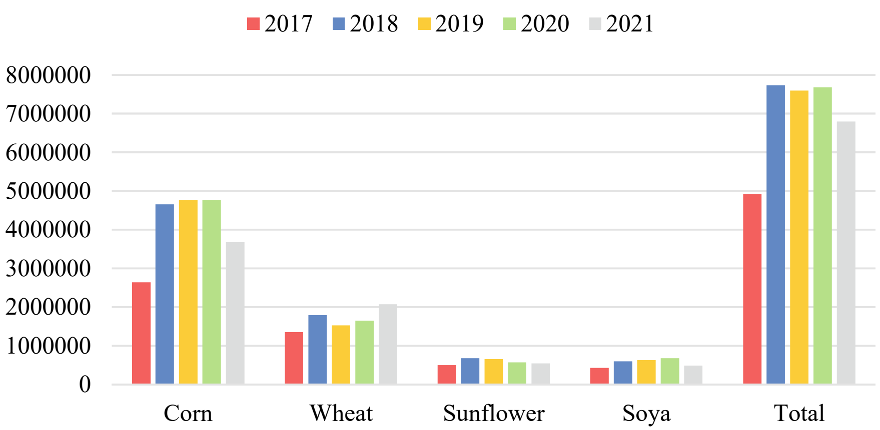

Fig. 19.1 Production of major crops (in tons) in Vojvodina for period 2017–2021

in 2021 production decreased by 12%. Minor oscillations were observed in wheat, sunflower and soya production. Larger oscillations are identified in the corn production. Compared to 2017, crop production increased by 76% in 2018, while in 2021 production decreased by 23%, compared to 2020. The corn production may vary significantly from year to year due to droughts that occasionally occur in the middle or in the end of summer and dramatically reduce production (in some cases by more than 50%) [18].

Table 19.1 presents the average annual agricultural biomass potential for ash production, in terms of amounts of ash that could be teoretically generated by combustion of analyzed agricultural biomass.

Presented data indicate the annual potential of over 2.4 million tons of agricultural biomass available for energy purposes in Vojvodina.

Industrial crops (sunflower and soya) have twice the volume of biomass than cereals (wheat and corn) in relation to the main product. However, as corn and wheat are the dominant agricultural crops, their residues account for 70.6% of the total analyzed biomass, with the ratio of corn biomass (stalk and cob) and wheat straw of 2.4.

The potentially available amount of ash that could be generated annually by combustion of analyzed biomass is estimated at over 196 thousand tons. In the context of determined amounts, corn stalk has the greatest theoretical potential for ash generation (40.1%), followed by wheat straw (20.5), sunflower stalks and head (14.5%), soy straw (13.8%) and corn cob (10%). Sunflower husk has the lowest theoretical potential (1.1%).

Table 19.1 The potentially available amounts of ash that could be generated annualy by combustion of analyzed agricultural biomass (for the 2017–2021 observation period)

Agricultural crop	The total product yield (t) [16, 17]	Product/ Biomass [19]	Biomass in the fields (t)	Biomass for combustion (t)	Biomass ash	
					(%)	(t)
	1	2	3 (1/2)	4 (3·30%)	5	6 (4·5/100)
Corn (stalk + cob)	4 106 000	1	4 106 000	1 231 800	8	98 544
Corn cob	–	5	821 200	246 360	8	19 709
Wheat	1 681 290	1	1 681 290	504 387	8	40 351
Sunflower (stalk + head)	592 738	0.5	1 185 476	355 643	8	28 452
Sunflower husk	–	4	147 185	44 456	5	2 223
Soya	566 460	0.5	1 132 920	339 876	8	27 191
Total	**6 946 489**	–	**8 253 871**	**2 476 162**		**196 759**

Although corn stalks have the largest share in the structure of the generated biomass, in addition to the stability of corn production, their potential is also questionable in terms of collection in the fields. Corn harvest is carried out in a period of frequent rainfall and low temperatures (October–November), which causes increased humidity, difficult drying and increased presence of dirt, in relation to other types of biomass.

Corn cobs have very good combustion characteristics, but their availability is limited due to the contemporary harvesting system, which involves harvesting corn in the grain, during which the cobs are broken and left in the fields. Harvesting corn on the cob is considered outdated and is less common in Serbia, compared to harvesting in the grain.

Sunflower seeds are usually harvested in September. After the harvest, the parts of heads and stalk mass comminuted with the combine are scattered over the field surface, and it is very difficult to collect such biomass [20]. At this stage, the sunflower stalk has high moisture (15–20%) and a very high ash content (10%) [18], which limits its use in energy production. Sunflower husks as production residues after oil extrusion have low moisture (9%), good and better thermal properties than stalk and heads and low ash content (ca. 2%) [21].

In the context of conducted research, wheat straw has been identified as agricultural biomass that has the greatest real potential for ash production, as agricultural biomass that is available in significant quantities and is most often used as a fuel, as well as it can be characterized by production stability. Soya straw is also identified by significant potential, due to the most optimal combustion properties, available quantities and production stability. Wheat is harvested in June–July, soya in September and collection of their residues can be carried out efficiently with appropriate mechanization.

19.3.2 Availability of Agricultural Biomass Ash

Twelve companies that use harvest residues as an energy source for obtaining thermal energy have been identified in the area of interest (Fig. 19.2). Data on used biomass types and generated quantities of biomass ash per year are presented in Table 19.2.

The available amount of biomass ash in the researched area of Vojvodina is over 4.2 thousand tons annually basis, which indicates an extremely low utilization (~2%) of the biomass potential determined in the first part of the research (196 thousand tons of ash).

Which type of ash will dominate the available ash structure depends on the climatic conditions and agricultural crop production. Most of the identified companies (7/12) use more than one type of biomass, which are usually mixed during combustion and which makes it difficult to determine the amount of ash by type. Consequently, a mixture of different types of ash dominates the available ash structure.

Five companies use one specific type of biomass—sunflower husk (two companies), soya straw (two companies) or corn cob (one company). Although sunflower

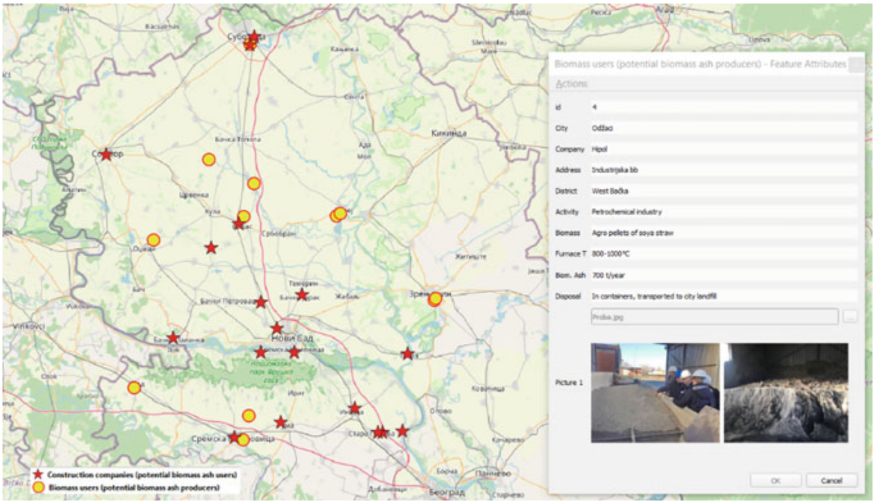

Fig. 19.2 Agricultural biomass users (potential biomass ash producers) and construction companies (potential users of biomass ash) identified in the Vojvodina region, with integrated data

Table 19.2 Identified quantities of biomass ash in Vojvodina [adapted from 22]

Company	Biomass type	Biomass ash (t/y)	Company	Biomass type	Biomass ash (t/y)
Sojaprotein	WS, SS, SW	1100	KNOTT Autoflex	WS, SS	60
ALMEX-IPOK	WS, SS, SH, CC	1100	PTK Panonija Mecker	WS, SS	60
Victoria oil	SH	720	Sava Kovačević	CC	30
Hipol	SS	700	Mitrosrem	WS, SS	15
Heating plant	SH	240	Victoria Starch	WS, SS	9
The veterinary institute	WS, SS	240	DTD Ribarstvo	SS	9
Total					**4 283**

WS—wheat straw, SS—soya straw, SH—sunflower husk, SW—silo waste (sunflower husk, soya husk and silo dust)

husk has the smallest share in the structure of available biomass, it is used in a significant amount—sunflower husk ash accounts for almost a quarter (22.4%) of the total available ash. Soya straw has a share of 16.5%. Only one identified company uses corn cob for energy production, which results in the smallest share of corn cob ash (0.7%) in the total amount of available ash. The small share of corn cob was expected based on the assessment of its potential, carried out in the first part of the research.

The use of corn stalks and sunflower stalks and heads is practically negligible in the identified companies.

Based on the analysis of biomass ash disposal, it was determined that generated ash is mostly deposited in containers for these purposes and transported to municipal landfills. Only a small amount of ash is deposited on the unregulated landfill within the company and is usually mixed with other waste materials.

19.3.3 Capacity for the Production of Cement Composites Based on Agricultural Biomass Ash

Eighteen active companies that produce precast concrete elements were identified in the area of interest (Fig. 19.2) [14], however the further analysis included only six companies (1/3), which were ready to provide the requested data.

In the analyzed companies, the average annual consumption of cement is 13,936 t.

Figure 19.3 compares the amounts of currently available agricultural biomass ash and the potential average annual savings of cement in case of partial replacement (10–50%) with ash. On an annual basis, total amount of currently available biomass ash produced in Vojvodina can be used for partial cement substitution up to 30% in six construction companies for production of precast concrete.

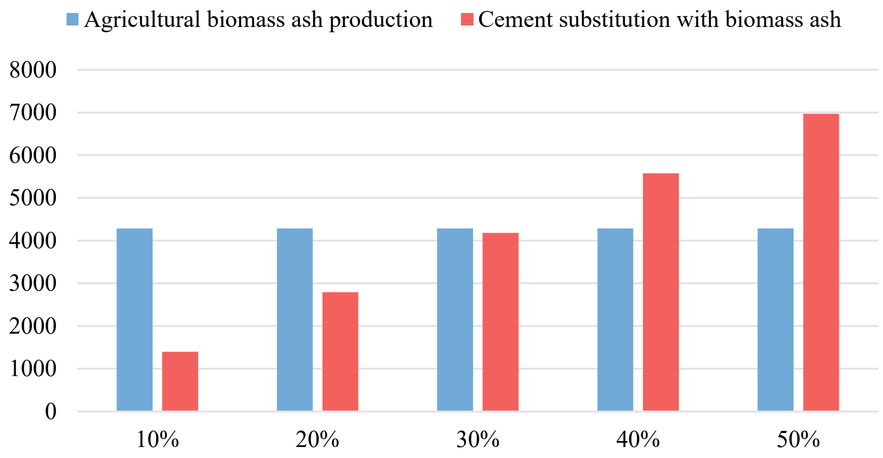

Fig. 19.3 The ratio of the total available amount of biomass ash and the required amount of ash for partial cement substitution (10–50%) in tons/year for 6 companies included in the analysis

19.4 Conclusion

Conducted research indicates the annual potential of over 2.4 million tons of harvest residues from corn, wheat, soya and sunflower, available for energy purposes in Vojvodina region. Nevertheless, enormous quantities remain unused in landfills or burned by households. By selling the biomass to industry, agriculturists would solve the problem of their waste disposal and also would make a profit. Biomass is cheaper than the commonly used fuel types and by its introduction as energy source, industry would benefit as well.

The potentially available amount of agricultural biomass ash that might be generated annually by combustion is estimated at over 196 thousand tons. Identified available amount of biomass ash (4.2 thousand tons) indicates an extremely low utilization (~2%) of the biomass potential. In addition, determination of the amount of ash by type can be challenging, as most of the companies usually mix different biomass types during combustion. On an annual basis, all current biomass ash production can be used for partial cement substitution up to 30% in six construction companies. However, the generated ash is mostly disposed of in municipal landfills, which represents the end of the waste stream. Networking of industry and construction companies would introduce a possibility of biomass ash use in civil engineering structures as an integral part of building construction. Acknowledging the possibility of ash application in civil engineering would give a new value to this type of waste and thus solve the problem of its disposal.

Identifying waste streams is an essential component of waste management plan development. The integration of all collected data and the results of the conducted research into a common database within the QGIS program enabled the establishment of multi-level georeferenced interactive map. The incorporated database provides the review, editing, analysis and update of geospatial data on the produced quantities of biomass ash and cement consumption in Vojvodina. The database can be connected to the Internet and become a publicly available database, which would enable an easy and simple review for all stakeholders.

The following research phase involves the characterization of biomass ashes as SCM. This phase upgrades the established database by providing more information on the quality of analysed biomass ash types.

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