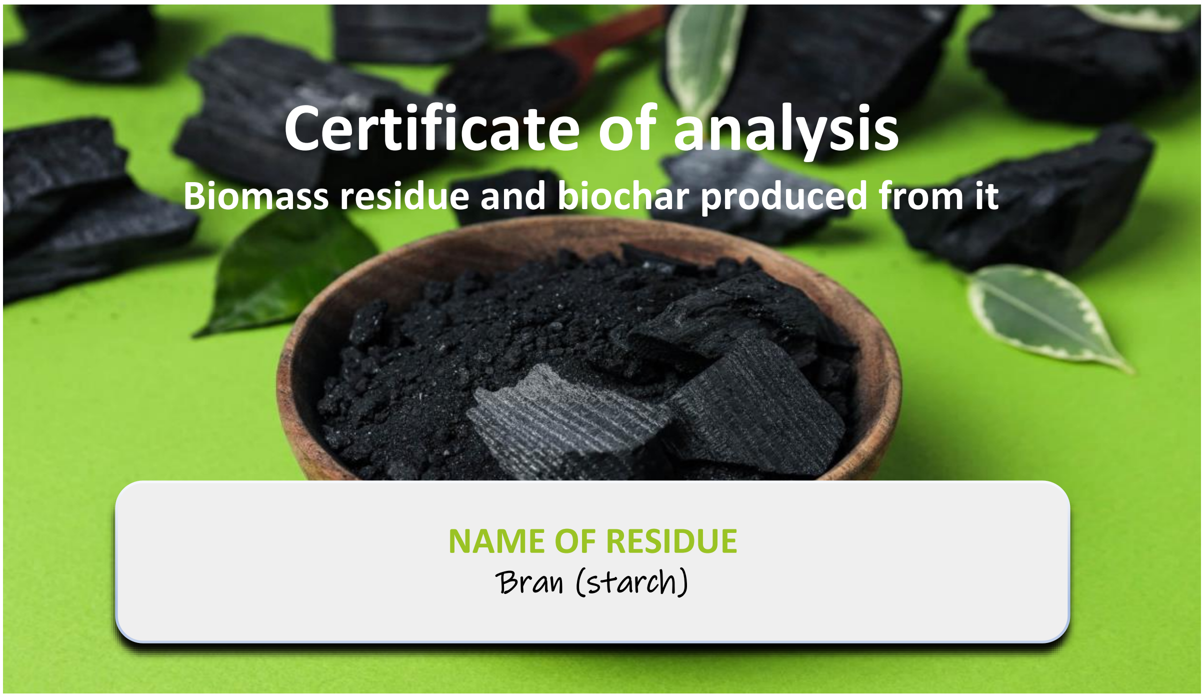
Interreg Alpine Space | Co-funded by the European Union | Alps4GreenC



1 Introduction

Alps4GreenC aims at implementing transnational value-chains in the Alpine territories to facilitate the development and implementation of bio-economy focusing mainly on the sustainable production and utilization of green carbon especially, biochar. In the course of the activity 1.3 - Practical testing and pilot production of green carbon a certificate of analysis was prepared. This certificate presents the biomass residue analysis results, the biomass conversion technology adopted, and the biochar analysis results. The biomass residues were kindly provided by the participants in the crowdsourcing campaign.
The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sustainable Technologies GmbH (BEST) and gasification Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

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2 Description of the biomass residue bran

The ***bran (starch)*** (Figure 1) is a by-product of starch production and was provided by the Agrana Research & Innovation Center.

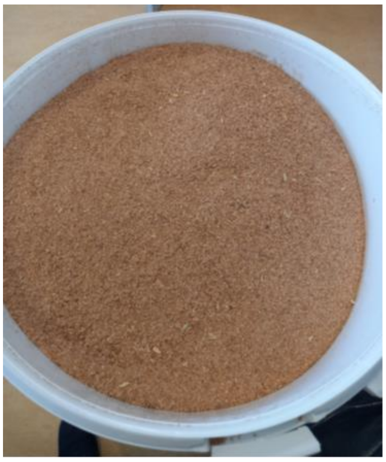


Figure 1: The bran (starch), photo credits: BEST

The bran (starch) residue was analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue biocharacterization, Heavy metal and inorganic nutrient contents and Particle size analysis;
General residue biocharacterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value and bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue biocharacterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue biocharacterisation

Paramter	Unit	Result	Method
Moisture content	w-% d.b.	10.70 ±0.56	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% d.b.	7.08 ±0.87	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	386 ±23	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	4.5 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	4.2 ±0.1	ISO 18125:2018
Carbon	w-% d.b.	44.2	ISO16948 2015
Chlorine	w-% d.b.	0.06 ±0.02	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% d.b.	6.4	ISO16948: 2015
Oxygen	w-% d.b.	39.6	calculated - by difference
Nitrogen	w-% d.b.	2.5 ±0.3	ISO16948: 2015
Sulphur	w-% d.b.	0.18 ±0.06	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2	
Total chromium	Cr	w-% d.b.	0.4 ±0.1	
Manganese	Mn	w-% d.b.	101.5 ±17.2	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	0.9 ±0.3	
Lead	Pb	w-% d.b.	< 0.2	
Copper	Cu	w-% d.b.	11.5 ±3.2	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	97.9 ±16.5	
Phosphorus	P	w-% d.b.	13259.0 ±2240.8	
Potassium	K	w-% d.b.	12392.7 ±2094.4	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	99.88	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	0	
Fraction 16 - 31.5 mm	w-%	0	
Fraction 31.5 - 45 mm	w-%	0	
Fraction 45 - 63 mm	w-%	0	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	0	
Sum in %	%	99.88	

3 Biochar production

The production of biochar from bran was performed using thermochemical technology p**yrolysis**.

<u>The experimental setup</u>

The lab-scale pyrolysis (Figure 2) was performed on a rotary kiln, located at BEST in Wieselburg, Lower Austria.

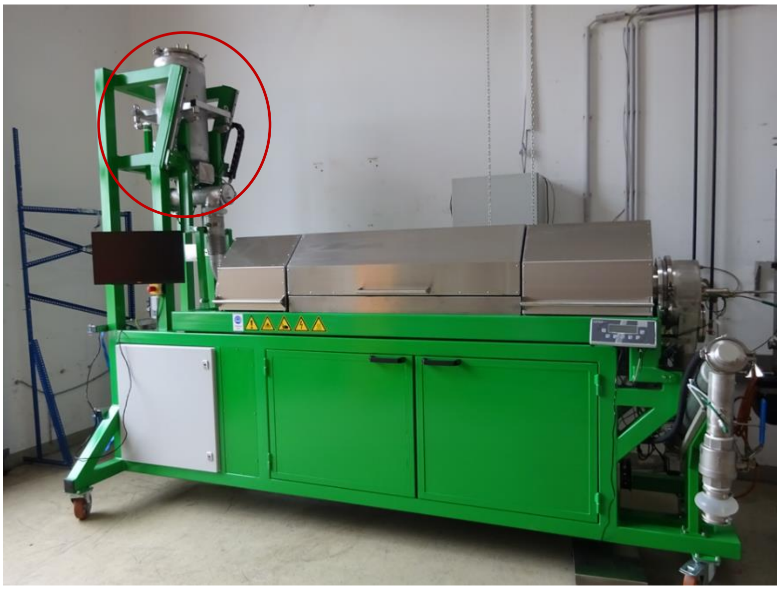


Figure 2: The used rotary kiln system, with the feedstock storage marked in red.

4 Biochar biocharacterization and results

The biochar samples were biocharacterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab srl. Biochar biocharacterizations performed at Water & Life Lab srl were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, moisture content, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar biocharacterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar biocharacterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to Table 6.

Table 4: Biochar biocharacterisation results

Parameter	Unit	Result	Method
Moisture content	%wt	4.68	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	$\%wt_{dry}$	23.79	ISO 14820-2: 2016 CEN/TS 17773:2022
C	$\%wt_{dry}$	62.19	Elementar analyser - Vario MACRO Cube
H	$\%wt_{dry}$	1.96	
N	$\%wt_{dry}$	3.92	
S	$\%wt_{dry}$	0.29	
O	$\%wt_{dry}$	7.85	
HHV_{Milne}	MJ/kg	22.0	Milne's formula
LHV_{Milne}	MJ/kg	21.6	
Water holding capacity	g/g	2.9	ISO 14238: 2014 annex A
Residual at 105°C	%wt	96	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%wt	4	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	16.3	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	416	CEN/TS 17758: 2022
pH @ 23.7 °C	$-\log_{10}(c(H^+))$	6.723	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

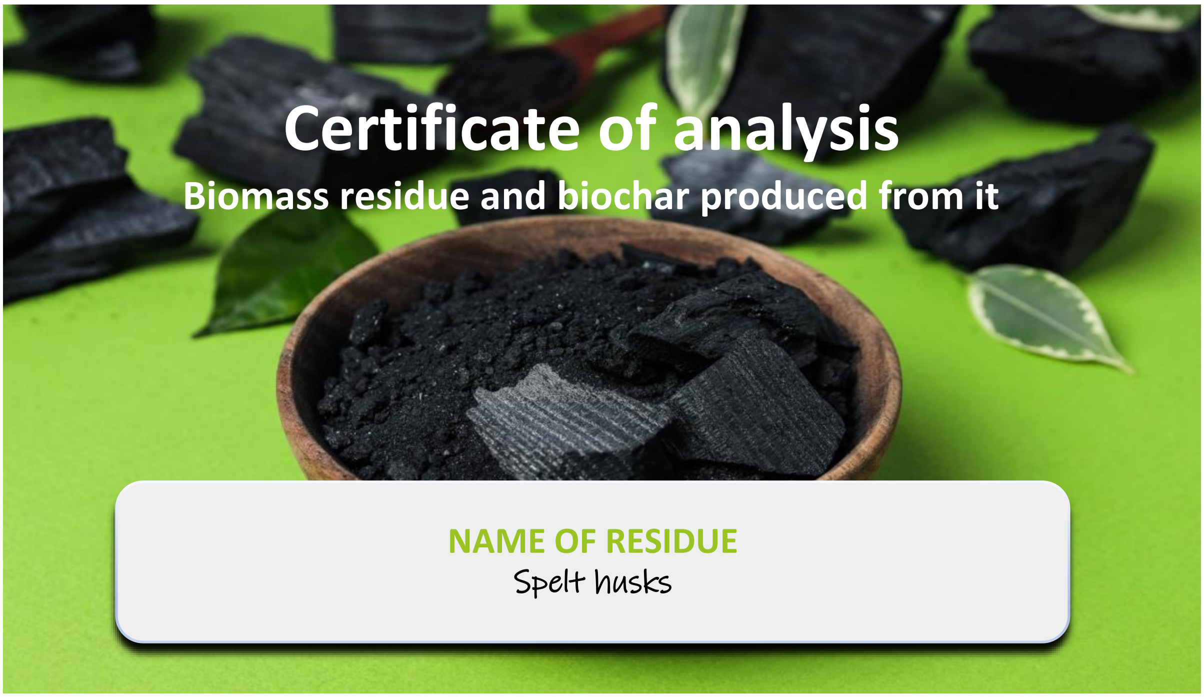
Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	11.4	
Phosphorus	P	mg/kg d.b.	49 119.7	
Manganese	Mn	mg/kg d.b.	334.3	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	5.1	
Nickel	Ni	mg/kg d.b.	8.2	
Lead	Pb	mg/kg d.b.	< 0.5	
Potassium	K	mg/kg d.b.	37 190.5	
Copper	Cu	mg/kg d.b.	28.5	
Thallium	Tl	mg/kg d.b.	< 1	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	298.8	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kg d.b.	0.07	CEN/TS 1618: 2018
Acenaphthylene	mg/kg d.b.	0.02	
Anthracene	mg/kg d.b.	0.37	
Benzo(a)anthracene	mg/kg d.b.	0.17	
Benzo(a)pyrene	mg/kg d.b.	0.10	
Benzo(b)fluoranthene	mg/kg d.b.	0.06	
Benzo(ghi)perylene	mg/kg d.b.	0.04	
Benzo(k)fluoranthene	mg/kg d.b.	0.02	
Chrysene	mg/kg d.b.	0.34	
Dibenzo(a,h)anthracene	mg/kg d.b.	0.03	
Phenanthrene	mg/kg d.b.	1.25	
Fluoranthene	mg/kg d.b.	0.40	
Fluorene	mg/kg d.b.	0.46	
Indeno(1,2,3-cd)pyrene	mg/kg d.b.	0.02	
Naphthalene	mg/kg d.b.	0.13	
Pyrene	mg/kg d.b.	0.47	
Total EPA-PAH (by calculation)	mg/kg d.b.	4.08	
Total EFSA-PAH (by calculation)	mg/kg d.b.	0.8	

5 Discussion

The produced biochar has some up and some downsides regarding its application in different industries. For the steel industry it is deemed as not very useful due to its high ash content and its low heating values and carbon content (ISBN 978-3-658-03688-1). For the agricultural application on the other hand, the biochar does show some promising properties. It has very low concentrations in heavy metals, while at the same time its potassium and phosphorous concentrations are very high. This would make it ideal as a soil amendment or fertilizing agent. Only the zinc content is a bit high, preventing the biochar from being used in organic agriculture or as a feed additive according to the EBC (https://www.european-biochar.org/media/doc/2/version_en_10_1.pdf). Regarding the process itself, a few issues occurred during processing. For further experiments the condensation of condensables during the process has to be minimized to increase the pH of the biochar and lower the PAH concentrations. Additionally, the bran in its powdery form is not suitable for pyrolysis in a rotary kiln, due to agglomeration in the reactor and subsequent material build up on the reactor wall. To resolve this, it is advised to either change reactor type (with screw or better twin-screw reactors being promising continuous alternatives) or to do the agglomeration in advance in the form of pelletisation or similar processes.



Certificate of analysis

Biomass residue and biochar produced from it

NAME OF RESIDUE

Spelt husks

1 Introduction

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The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sustainable Technologies GmbH (BEST) and gasification Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

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2 Description of the biomass residue spelt husks

The ***spelt husks*** (Figure 1) is produced in agriculture during the spelt harvest and were provided by from the organic farmer Mr. Karl Brader in Lower Austria.

Figure 1: The spelt husks, photo credits: BEST

The spelt husks were analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;
General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value and bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% d.b.	10.01 ±0.52	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% d.b.	7.05 ±0.87	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	153 ±9	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	4.3 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	4.0 ±0.1	ISO 18125:2018
Carbon	w-% d.b.	43.4	ISO16948 2015
Chlorine	w-% d.b.	0.008	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% d.b.	5.8	ISO16948: 2015
Oxygen	w-% d.b.	43.2	calculated - by difference
Nitrogen	w-% d.b.	0.4 ±0.1	ISO16948: 2015
Sulphur	w-% d.b.	0.07 ±0.03	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2	
Total chromium	Cr	w-% d.b.	2.1 ±0.5	
Manganese	Mn	w-% d.b.	11.9 ±2.0	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	1.0 ±0.3	
Lead	Pb	w-% d.b.	< 0.2	
Copper	Cu	w-% d.b.	1.5 ±0.4	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	9.1 ±1.5	
Phosphorus	P	w-% d.b.	1892.2 ±319.8	
Potassium	K	w-% d.b.	3342.5 ±564.9	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	87.38	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	12.62	
Fraction 16 - 31.5 mm	w-%	0	
Fraction 31.5 - 45 mm	w-%	0	
Fraction 45 - 63 mm	w-%	0	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	0	
Sum in %	%	100	

3 Biochar production

The production of biochar from spelt husks was performed using thermochemical technology **gasification**.

<u>The experimental setup</u>
The experiments on a lab-scale gasifier (Figure 2) were conducted on a reverse updraft batch reactor at the Free University of Bozen-Bolzano, Italy.

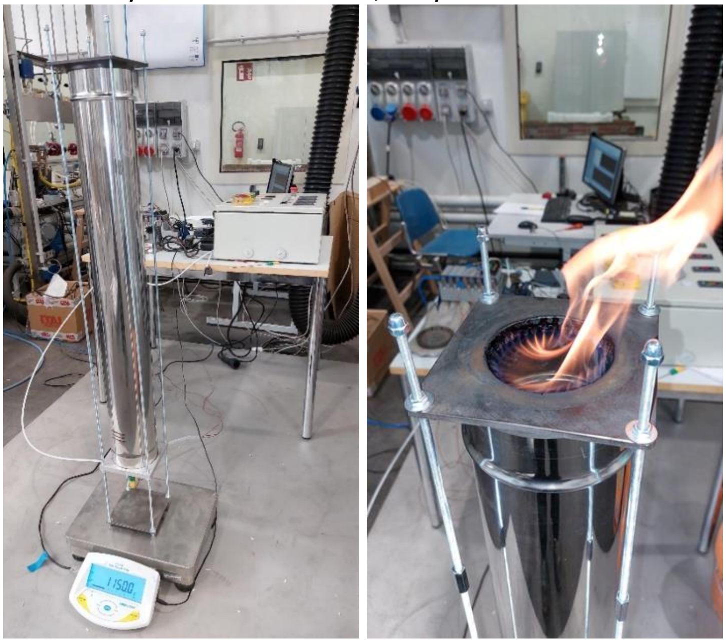

Figure 2: Lab-scale gasifier – mounted on weighing scale (L), during operation (R)

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab srl. Biochar characterizations performed at Water & Life Lab srl were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, moisture content, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to Table 6.

Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	%wt	3.14	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	$\%wt_{dry}$	39.68	ISO 14820-2: 2016 CEN/TS 17773:2022
C	$\%wt_{dry}$	57.16	Elementar analyser - Vario MACRO Cube, Elementar
H	$\%wt_{dry}$	0.89	
N	$\%wt_{dry}$	0.45	
S	$\%wt_{dry}$	0.09	
O	$\%wt_{dry}$	1.73	
HHV_{Milne}	MJ/kg	19.81	Milne’s formula
LHV_{Milne}	MJ/kg	19.62	
Water holding capacity	g/g	6.0	ISO 14238: 2014 annex A
Residual at 105°C	%	98	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	2	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	18.8	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	354	CEN/TS 17758: 2022
pH @ 24.0 °C	$-\log_{10}(c(H^+))$	9.258	*European Biochar Certificate (EBC)* guideline

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Table 5: Heavy metal and inorganic nutrients of the biochar

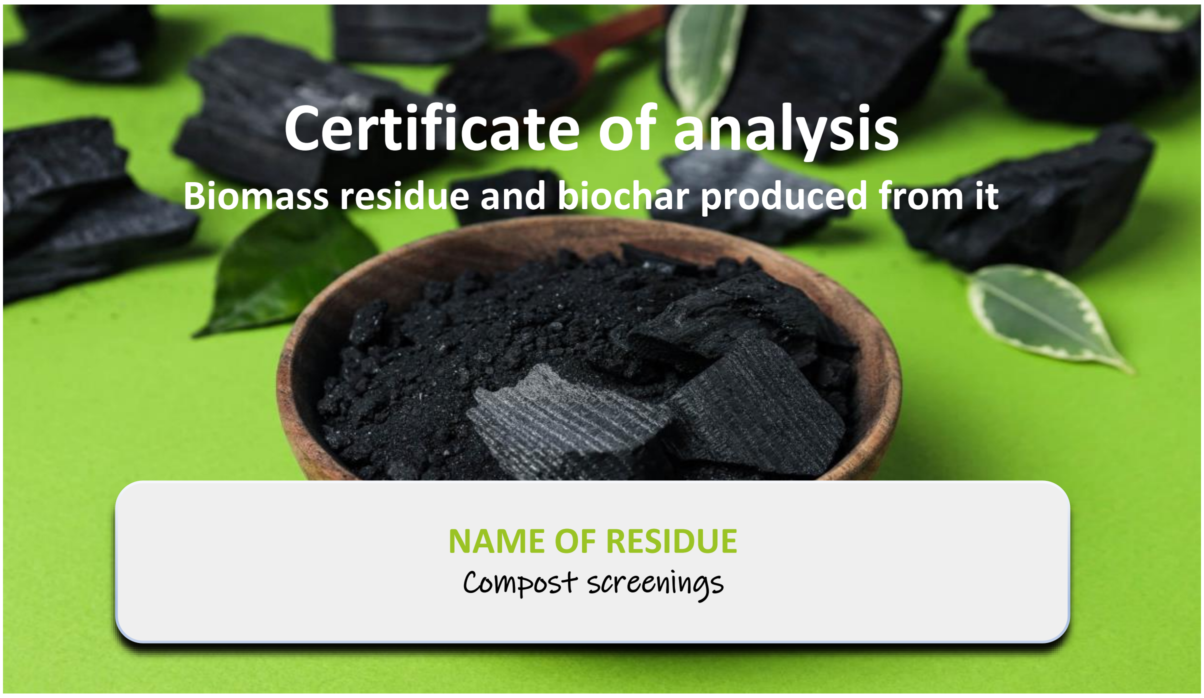
Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	16.4	
Phosphorus	P	mg/kg d.b.	2 179.9	
Manganese	Mn	mg/kg d.b.	87.3	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	0.7	
Nickel	Ni	mg/kg d.b.	7.7	
Lead	Pb	mg/kg d.b.	0.8	
Potassium	K	mg/kg d.b.	7 299.6	
Copper	Cu	mg/kg d.b.	2.2	
Thallium	Tl	mg/kg d.b.	< 0.5	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	20.5	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kgd.b.	< 0.01	CEN/TS 1618: 2018
Acenaphthylene	mg/kgd.b.	< 0.01	
Anthracene	mg/kgd.b.	< 0.01	
Benzo(a)anthracene	mg/kgd.b.	< 0.01	
Benzo(a)pyrene	mg/kgd.b.	< 0.01	
Benzo(b)fluoranthene	mg/kgd.b.	< 0.01	
Benzo(ghi)perylene	mg/kgd.b.	< 0.01	
Benzo(k)fluoranthene	mg/kgd.b.	< 0.01	
Chrysene	mg/kgd.b.	< 0.01	
Dibenzo(a,h)anthracene	mg/kgd.b.	< 0.01	
Phenanthrene	mg/kgd.b.	< 0.01	
Fluoranthene	mg/kgd.b.	< 0.01	
Fluorene	mg/kgd.b.	< 0.01	
Indeno(1,2,3-cd)pyrene	mg/kgd.b.	< 0.01	
Naphthalene	mg/kgd.b.	0.22	
Pyrene	mg/kgd.b.	< 0.01	
Total EPA-PAH (by calculation)	mg/kgd.b.	< 0.01	
Total EFSA-PAH (by calculation)	mg/kgd.b.	<0.01	

5 Discussion

The produced char is deemed as not very attractive for the application in the steel industry due to its high ash content and low heating values and carbon content (ISBN 978-3-658-03688-1). However, the char shows promising properties for the application as a soil amendment in the agriculture. It has very low levels of heavy metals and PAH pollutants, while at the same time having considerable concentrations in potassium and phosphorus. The char has a high pH which could make it ideal for the application in acidic soils (DOI: 10.1111/gcbb.12889) and it showed the highest water holding capacity of all the produced biochars. Due to its very low atomic H/C ratio it could even be an attractive choice for the application as a feed additive (https://www.european-biochar.org/media/doc/2/version_en_10_1.pdf).



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2 Description of the biomass residue compost screenings

The ***compost screenings*** (Figure 1) are a by-product of compost processing and were provided by the company Brantner green solutions.

Figure 1: The compost screenings, photo credits:BEST

The compost screenings were analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;
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Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% d.b.	7.07 ±0.37	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% d.b.	16.94 ±2.08	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	231 ±14	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	4.4 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	4.5 ±0.1	ISO 18125:2018
Carbon	w-% d.b.	42.0	ISO16948 2015
Chlorine	w-% d.b.	0.58 ±0.11	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% d.b.	5.2	ISO16948: 2015
Oxygen	w-% d.b.	33.2	calculated - by difference
Nitrogen	w-% d.b.	1.6 ±0.2	ISO16948: 2015
Sulphur	w-% d.b.	0.24 ±0.08	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	1.6 ±0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	0.2 ±0.1	
Total chromium	Cr	w-% d.b.	15.3 ±3.8	
Manganese	Mn	w-% d.b.	195.1 ±33.0	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	6.2 ±1.8	
Lead	Pb	w-% d.b.	4.5 ±1.1	
Copper	Cu	w-% d.b.	18.2 ±5.1	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	58.7 ±9.9	
Phosphorus	P	w-% d.b.	2169.5 ±366.7	
Potassium	K	w-% d.b.	13001.5 ±2197.3	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	33.06	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	57.82	
Fraction 16 - 31.5 mm	w-%	6.37	
Fraction 31.5 - 45 mm	w-%	1.93	
Fraction 45 - 63 mm	w-%	0	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	0	
Sum in %	%	99.18	

3 Biochar production

The production of biochar from compost screenings was performed using thermochemical technology **pyrolysis**.

<u>The experimental setup</u>

The lab-scale pyrolysis (Figure 2) was performed on a rotary kiln, located at BEST in Wieselburg, Lower Austria.

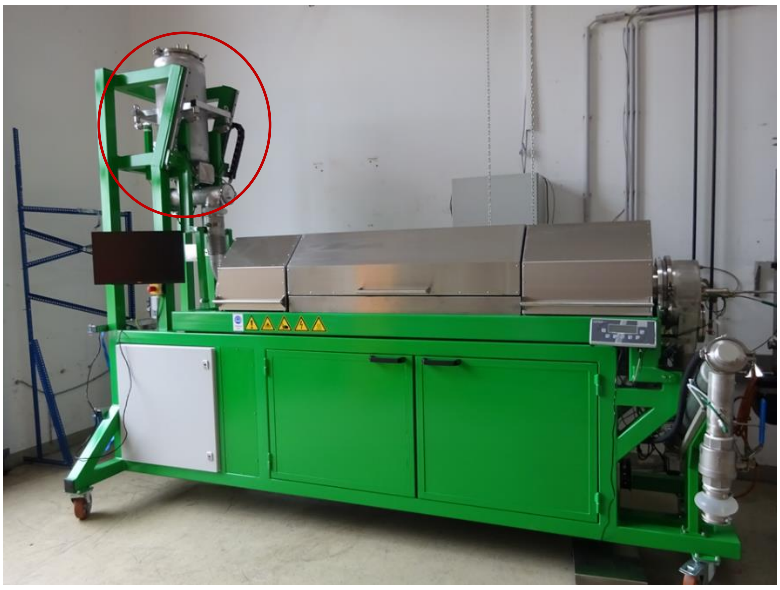

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Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	%wt	8.28	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	$\%wt_{dry}$	33.14	ISO 14820-2: 2016 CEN/TS 17773:2022
C	$\%wt_{dry}$	49.02	Elementar analyser - Vario MACRO Cube, Elementar
H	$\%wt_{dry}$	1.98	
N	$\%wt_{dry}$	2.23	
S	$\%wt_{dry}$	0.35	
O	$\%wt_{dry}$	13.29	
HHV_{Milne}	MJ/kg	16.98	Milne's formula
LHV_{Milne}	MJ/kg	16.55	
Water holding capacity	g/g	2.2	ISO 14238: 2014 annex A
Residual at 105°C	%	91	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	9	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	24.3	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	7 166	CEN/TS 17758: 2022
pH @ 27.4 °C	$-\log_{10}(c(H^+))$	9.408	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	1.8	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	42.8	
Phosphorus	P	mg/kg d.b.	4 308.9	
Manganese	Mn	mg/kg d.b.	349.6	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	5.9	
Nickel	Ni	mg/kg d.b.	22.7	
Lead	Pb	mg/kg d.b.	10.2	
Potassium	K	mg/kg d.b.	27 388.8	
Copper	Cu	mg/kg d.b.	35.1	
Thallium	Tl	mg/kg d.b.	< 1	
Vanadium	V	mg/kg d.b.	16.6	
Zinc	Zn	mg/kg d.b.	118.2	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kgd.b.	0.40	CEN/TS 1618: 2018
Acenaphthylene	mg/kgd.b.	0.09	
Anthracene	mg/kgd.b.	0.45	
Benzo(a)anthracene	mg/kgd.b.	0.18	
Benzo(a)pyrene	mg/kgd.b.	0.06	
Benzo(b)fluoranthene	mg/kgd.b.	0.05	
Benzo(ghi)perylene	mg/kgd.b.	0.03	
Benzo(k)fluoranthene	mg/kgd.b.	0.02	
Chrysene	mg/kgd.b.	0.27	
Dibenzo(a,h)anthracene	mg/kgd.b.	0.02	
Phenanthrene	mg/kgd.b.	2.51	
Fluoranthene	mg/kgd.b.	0.71	
Fluorene	mg/kgd.b.	1.52	
Indeno(1,2,3-cd)pyrene	mg/kgd.b.	0.01	
Naphthalene	mg/kgd.b.	0.03	
Pyrene	mg/kgd.b.	0.54	
Total EPA-PAH (by calculation)	mg/kgd.b.	6.98	
Total EFSA-PAH (by calculation)	mg/kgd.b.	0.6	

5 Discussion

The produced biochar is deemed as not very attractive for the application in steel industry due to its high ash content and low heating values and carbon content (ISBN 978-3-658-03688-1). However, it shows promising properties for the application in agriculture. It is very low in heavy metals and shows high concentrations for the nutrient elements potassium and phosphorous which would make it ideal for the application as a soil amendment. It also has a high pH, which could be attractive for acidic soils (DOI: 10.1111/gcbb.12889) and it has one of the highest cation exchange capacities. However, the concentration of PAH pollutants would prevent it from being used that way right now (https://www.european-biochar.org/media/doc/2/version_en_10_1.pdf).

As the PAH concentrations is influenced to a large part by the process conditions, it is advised to choose more favourable conditions regarding PAH formation and contamination in the future. Additionally, as this residue is quite inhomogeneous by nature and its composition may change considerably over time, heavy metal levels might become an issue, if, for example, the metal fraction of the screening surplus increases.

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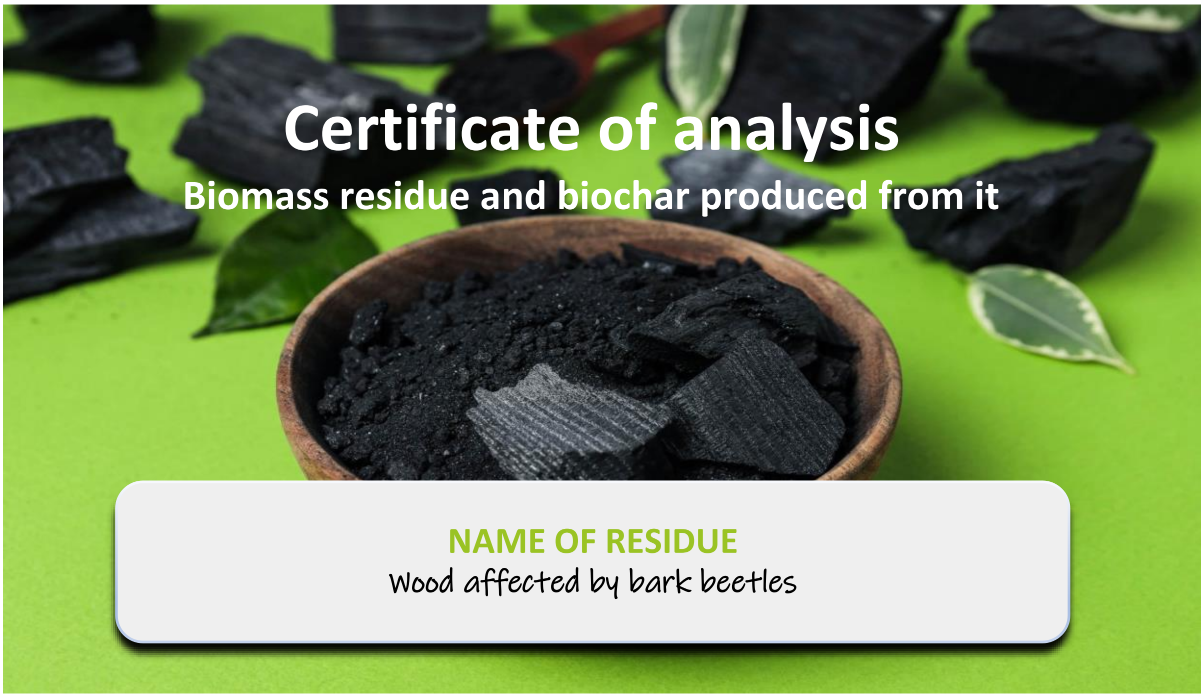

Certificate of analysis

Biomass residue and biochar produced from it

NAME OF RESIDUE

Wood affected by bark beetles

1 Introduction

Alps4GreenC aims at implementing transnational value-chains in the Alpine territories to facilitate the development and implementation of bio-economy focusing mainly on the sustainable production and utilization of green carbon especially, biochar. In the course of the activity 1.3 - Practical testing and pilot production of green carbon a certificate of analysis was prepared. This certificate presents the biomass residue analysis results, the biomass conversion technology adopted, and the biochar analysis results. The biomass residues were kindly provided by the participants in the crowdsourcing campaign.

The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification at the Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

This project is co-funded by the European Union through the Interreg Alpine Space programme

2 Description of the biomass residue: Wood affected by bark beetles

The ***wood affected by bark beetles (BW)*** (Figure 1) was provided by the company Dapoz Roland in Italy.

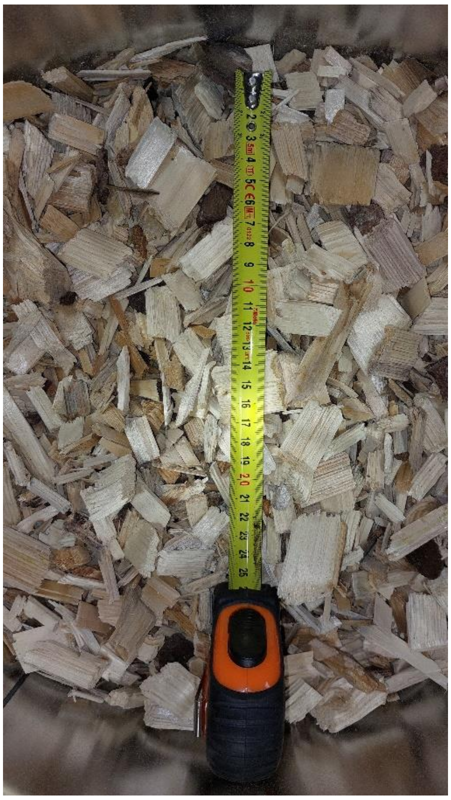

Figure 1: Wood affected by bark beetles

The bark beetle wood (BW) was analyzed by the *Water & Life Lab S.r.l., Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis; General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% d.b.	3.89 ±0.20	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% d.b.	0.96 ±0.12	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	185 ±11	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	5.4 ±0.2	ISO 18125:2018
Net calorific value	kWh/kg	5.1 ±0.2	ISO 18125:2018
Carbon	w-% d.b.	48.4	ISO16948 2015
Chlorine	w-% d.b.	0.01 ±0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% d.b.	6.1	ISO16948: 2015
Oxygen	w-% d.b.	44.4	calculated - by difference
Nitrogen	w-% d.b.	0.1 ±0.1	ISO16948: 2015
Sulphur	w-% d.b.	<0.01	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	0.4 ±0.1	
Total chromium	Cr	w-% d.b.	3.6 ±0.9	
Manganese	Mn	w-% d.b.	50.0 ±8.4	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	2.2 ±0.6	
Lead	Pb	w-% d.b.	3.0 ±0.7	
Copper	Cu	w-% d.b.	8.7 ±2.4	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	27.0 ±4.6	
Phosphorus	P	w-% d.b.	38.6 ±6.5	
Potassium	K	w-% d.b.	674.3 ±114.0	

Table 3: Particle size analysis results

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	3.3	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	31.5	
Fraction 16 - 31.5 mm	w-%	51.66	
Fraction 31.5 - 45 mm	w-%	9.8	
Fraction 45 - 63 mm	w-%	1.72	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	1.92	
Sum in %	%	99.9	
Coarse fraction over 31.5 mm	w-%	13.44	ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	3.64	
Coarse fraction over 63 mm	w-%	1.92	
Coarse fraction over 100 mm	w-%	1.92	

3 Biochar production

The production of biochar from bark beetle wood (BW) was performed using gasification technology, both at the laboratory and pilot scale.

<u>The experimental setup</u>

The experiments on a lab-scale gasifier were conducted on a reverse updraft batch reactor at the Free University of Bozen-Bolzano, Italy (Figure 2).

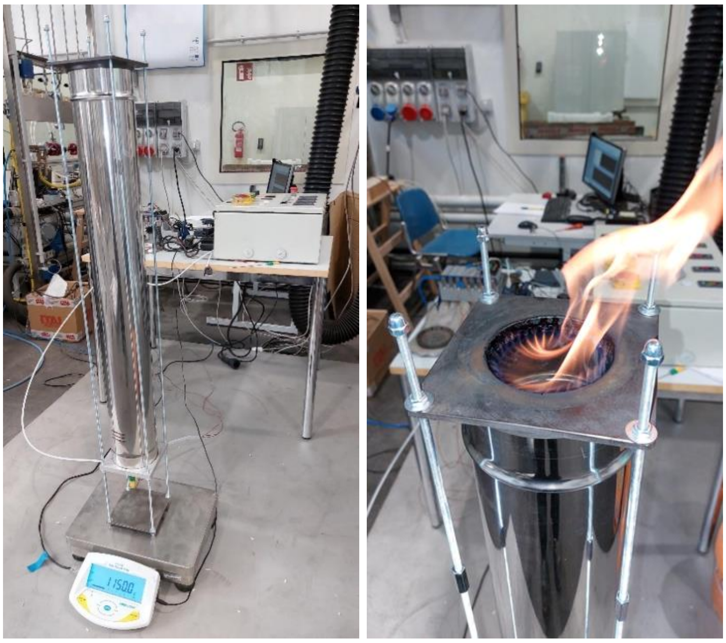

Figure 2: Lab-scale gasifier – mounted on weighing scale (L), during operation (R)

Experimental setup of the pilot-scale plant

The experiments were conducted on the pilot-scale gasification system at unibz (Figure 3).
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Figure 3: Pilot scale gasification setup

The biochar produced is shown in Figure 4.

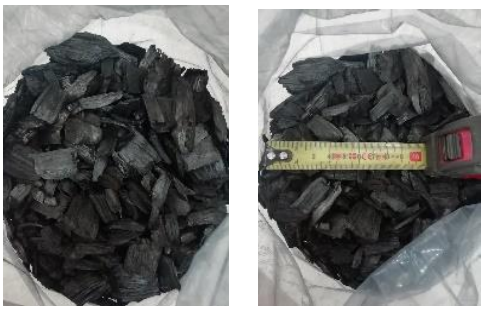

Figure 4: Biochar produced from gasification of the wood affected by bark beetles

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab S.r.l.. Biochar characterizations performed at Water & Life Lab S.r.L. were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to 8 for biochars obtained both at the lab- and pilot-scale.

Table 4: Biochar characterisation results

Parameter	Unit	Lab scale	Pilot scale	Method
Moisture content	w-%	2.03	2.05	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	w-% d.b	2.76	4.17	ISO 14820-2: 2016 CEN/TS 17773:2022
C	w-% d.b	81.72	87.21	Elementar analyser - Vario MACRO Cube, Elementar
H	w-% d.b	3.25	1.23	
N	w-% d.b	0.41	0.56	
S	w-% d.b	0.09	0.18	
O	w-% d.b	11.77	6.67	
HHV_{Milne}	MJ/kg	30.67	30.44	Milne's formula
LHV_{Milne}	MJ/kg	29.96	30.17	
Water holding capacity	g/g	5.3	2.6	ISO 14238: 2014 annex A
Residual at 105°C	%	98	100	ISO 14820-2:2016 CEN/TS 17773: 2022
Cation exchange capacity with $BaCl_2$	meq/100g	25.2	20.3	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	34	34	CEN/TS 17758: 2022
pH @ 23.1 °C for lab-scale, 25.1 °C for pilot-scale	$-\log_{10}(c(H^+))$	7.601	8.599	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Lab scale	Pilot scale	Method
Arsenic	As	mg/kg d.b.	< 1.0	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	< 0.5	
Total chromium	Cr	mg/kg d.b.	0.5	25.9	
Phosphorus	P	mg/kg d.b.	162.6	127.5	
Manganese	Mn	mg/kg d.b.	170.8	56.6	
Mercury	Hg	mg/kg d.b.	< 0.01	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	< 0.5	
Nickel	Ni	mg/kg d.b.	< 0.5	11.6	
Lead	Pb	mg/kg d.b.	< 0.5	< 0.5	
Potassium	K	mg/kg d.b.	2714.7	2791.9	
Copper	Cu	mg/kg d.b.	2.7	2.6	
Thallium	Tl	mg/kg d.b.	< 0.5	< 0.5	
Vanadium	V	mg/kg d.b.	< 2.5	< 2.5	
Zinc	Zn	mg/kg d.b.	48.7	36.1	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result		Method
Acenaphthene	mg/kgd.b.	< 0.01	0.90	CEN/TS 1618: 2018
Acenaphthylene	mg/kgd.b.	< 0.01	2.61	
Anthracene	mg/kgd.b.	< 0.01	0.29	
Benzo(a)anthracene	mg/kgd.b.	< 0.01	0.07	
Benzo(a)pyrene	mg/kgd.b.	< 0.01	0.05	
Benzo(b)fluoranthene	mg/kgd.b.	< 0.01	0.06	
Benzo(ghi)perylene	mg/kgd.b.	< 0.01	0.04	
Benzo(k)fluoranthene	mg/kgd.b.	< 0.01	< 0.01	
Chrysene	mg/kgd.b.	< 0.01	0.01	
Dibenzo(a,h)anthracene	mg/kgd.b.	< 0.01	0.02	
Phenanthrene	mg/kgd.b.	0.06	2.62	
Fluoranthene	mg/kgd.b.	< 0.01	0.52	
Fluorene	mg/kgd.b.	< 0.01	1.44	
Indeno(1,2,3-cd)pyrene	mg/kgd.b.	< 0.01	0.03	
Naphthalene	mg/kgd.b.	0.19	3.97	
Pyrene	mg/kgd.b.	< 0.01	0.55	
Total EPA-PAH (by calculation)	mg/kgd.b.	0.26	13.18	
Total EFSA-PAH (by calculation)	mg/kgd.b.	< 0.01	0.3	

Table 7: Results of the poly chlorinated diphenyls (PCB) measurements

PCB	Unit	Result	Method
PCB 28 (TriCB)	mg/kg	< 0.01	EPA 3550 C 2007 EPA 8270 E 2018
PCB 52 (TetraCB)	mg/kg	< 0.01	
PCB 77 (TetraCB)	mg/kg	< 0.01	
PCB 81 (TetraCB)	mg/kg	< 0.01	
PCB 91 (TetraCB)	mg/kg	< 0.01	
PCB 99 (PentaCB)	mg/kg	< 0.01	
PCB 101 (PentaCB)	mg/kg	< 0.01	
PCB 105 (PentaCB)	mg/kg	< 0.01	
PCB 110 (PentaCB)	mg/kg	< 0.01	
PCB 114 (PentaCB)	mg/kg	< 0.01	
PCB 128+123 (PentaCB)	mg/kg	< 0.01	
PCB 126 (PentaCB)	mg/kg	< 0.01	
PCB 128 (HexaCB)	mg/kg	< 0.01	
PCB 138 (HexaCB)	mg/kg	< 0.01	
PCB 146 (HexaCB)	mg/kg	< 0.01	
PCB 149 (HexaCB)	mg/kg	< 0.01	
PCB 151 (HexaCB)	mg/kg	< 0.01	
PCB 153 (HexaCB)	mg/kg	< 0.01	
PCB 156 (HexaCB)	mg/kg	< 0.01	
PCB 157 (HexaCB)	mg/kg	< 0.01	
PCB 167 (HexaCB)	mg/kg	< 0.01	
PCB 169 (HexaCB)	mg/kg	< 0.01	
PCB 170 (HeptaCB)	mg/kg	< 0.01	
PCB 177 (HeptaCB)	mg/kg	< 0.01	
PCB 180 (HeptaCB)	mg/kg	< 0.01	
PCB 183 (HeptaCB)	mg/kg	< 0.01	
PCB 187 (HeptaCB)	mg/kg	< 0.01	
PCB 189 (HeptaCB)	mg/kg	< 0.01	
PCB sums (D.Lgs. n. 121 del 03/09/2020) mg/kg < 0.01	mg/kg	< 0.01	
PCB sums (Reg. CE 2019/1021 e s.m.i.)	mg/kg	< 0.01	

Table 8: Results of the dioxins and furans measurements

DIOXINS AND FURANS	Unit	Result	Method
PCDD:			EPA 8280 B 2007
2,3,7,8 TCDD	µg/kg	< 0.0010	
1,2,3,7,8 PCDD	µg/kg	< 0.0050	
1,2,3,4,7,8 HxCDD	µg/kg	< 0.0050	
1,2,3,7,8,9 HxCDD	µg/kg	< 0.0050	
1,2,3,6,7,8 HxCDD	µg/kg	< 0.0050	
1,2,3,4,6,7,8 HpCDD	µg/kg	< 0.0050	
OCDD	µg/kg	< 0.0100	
PCDF:			
2,3,7,8 TCDF	µg/kg	0.0021	
2,3,4,7,8 PCDF	µg/kg	< 0.0050	
1,2,3,7,8 PCDF	µg/kg	< 0.0050	
1,2,3,4,7,8 HxCDF	µg/kg	< 0.0050	
1,2,3,7,8,9 HxCDF	µg/kg	< 0.0050	
1,2,3,6,7,8 HxCDF	µg/kg	< 0.0050	
2,3,4,6,7,8 HxCDF	µg/kg	< 0.0050	
1,2,3,4,6,7,8 HpCDF	µg/kg	< 0.0050	
1,2,3,4,7,8,9 HpCDF	µg/kg	< 0.0050	
OCDF	µg/kg	< 0.0100	
Sum of PCDD/PCDF	µg/kg	0.0059	

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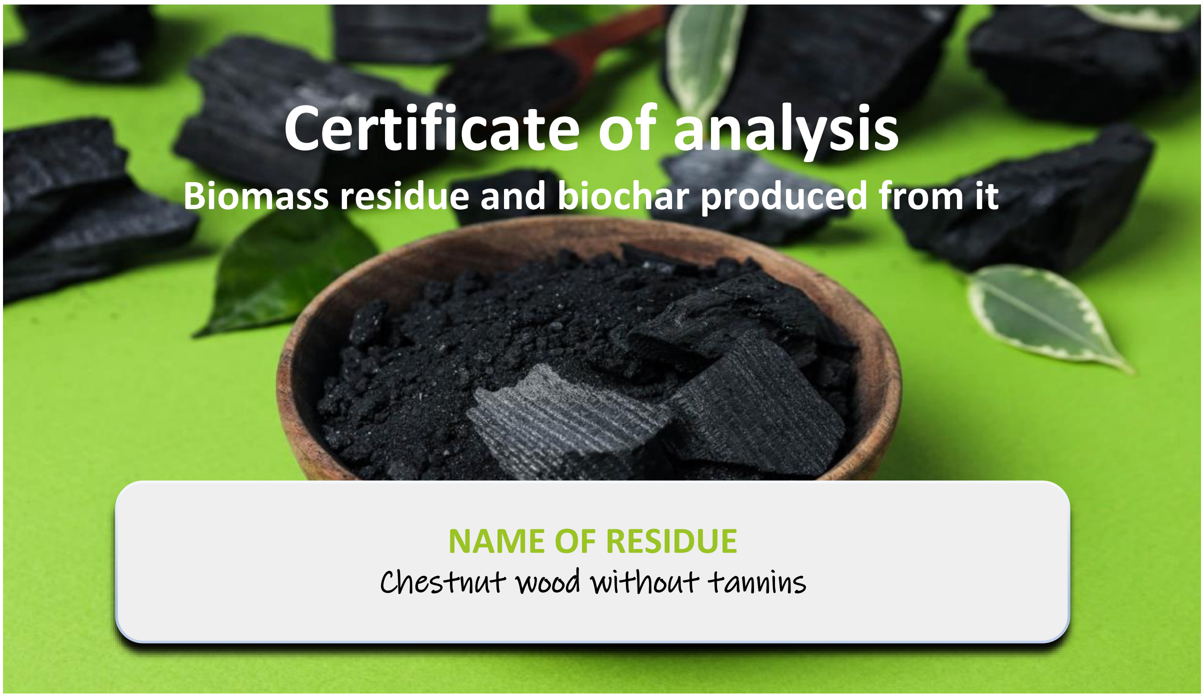


Certificate of analysis

Biomass residue and biochar produced from it

NAME OF RESIDUE

Chestnut wood without tannins

1 Introduction

Alps4GreenC aims at implementing transnational value-chains in the Alpine territories to facilitate the development and implementation of bio-economy focusing mainly on the sustainable production and utilization of green carbon especially, biochar. In the course of the activity 1.3 - Practical testing and pilot production of green carbon a certificate of analysis was prepared. This certificate presents the biomass residue analysis results, the biomass conversion technology adopted, and the biochar analysis results. The biomass residues were kindly provided by the participants in the crowdsourcing campaign.

The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification at the Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

2 Description of the biomass residue: Chestnut wood without tannins

The ***Chestnut wood without tannins*** (Figure 1) was provided by the company Ledoga *S.r.l.* in Italy.

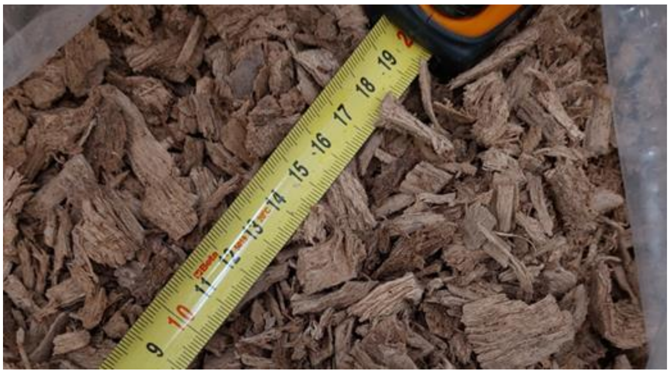


Figure 1: Chestnut wood without tannins

The Chestnut wood without tannins was analyzed by the *Water & Life Lab S.r.l., Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;

General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	39.56 ±2.06	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	0.69 ±0.09	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	275 ±16	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	3.1 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	2.8 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	48.3	ISO16948 2015
Chlorine	w-% $_{d.b.}$	0.01 ±0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	6.0	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	44.7	calculated - by difference
Nitrogen	w-% $_{d.b.}$	0.3 ±0.1	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.02 ±0.01	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2	
Total chromium	Cr	w-% d.b.	5.7 ±1.4	
Manganese	Mn	w-% d.b.	35.1 ±5.9	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	2.8 ±0.8	
Lead	Pb	w-% d.b.	0.8 ±0.2	
Copper	Cu	w-% d.b.	2.0 ±0.6	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	7.4 ±1.3	
Phosphorus	P	w-% d.b.	28.5 ±4.8	
Potassium	K	w-% d.b.	108.7 ±18.4	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	8.32	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	74.53	
Fraction 16 - 31.5 mm	w-%	15.55	
Fraction 31.5 - 45 mm	w-%	0.45	
Fraction 45 - 63 mm	w-%	0	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	0	
Sum in %	%	98.85	
Coarse fraction over 31.5 mm	w-%	0.45	ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	0	
Coarse fraction over 63 mm	w-%	0	
Coarse fraction over 100 mm	w-%	0	

3 Biochar production

The production of biochar from Chestnut wood without tannins was performed using gasification technology.

<u>The experimental setup</u>

The experiments on a lab-scale gasifier (Figure 2) were conducted on a reverse updraft batch reactor at the Free University of Bozen-Bolzano, Italy.

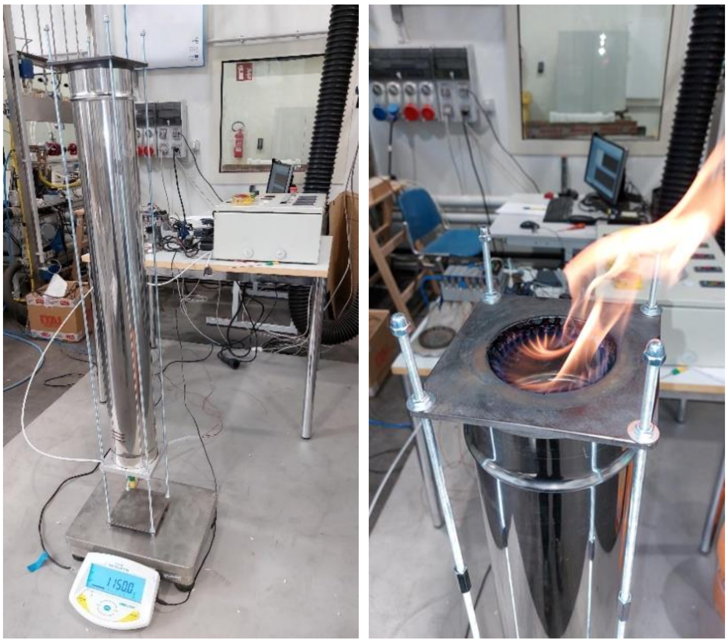


Figure 2: Lab-scale gasifier – mounted on weighing scale (L), during operation (R)

The biochar produced is shown in Figure 3.

Figure 3: Biochar produced from the gasification of chestnut wood without tannins

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab S.r.l.. Biochar characterizations performed at Water & Life Lab S.r.l. were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, cation exchange capacity, chlorides, PAH. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table Table 1 to Table 6.

Table 4: Biochar characterisation results

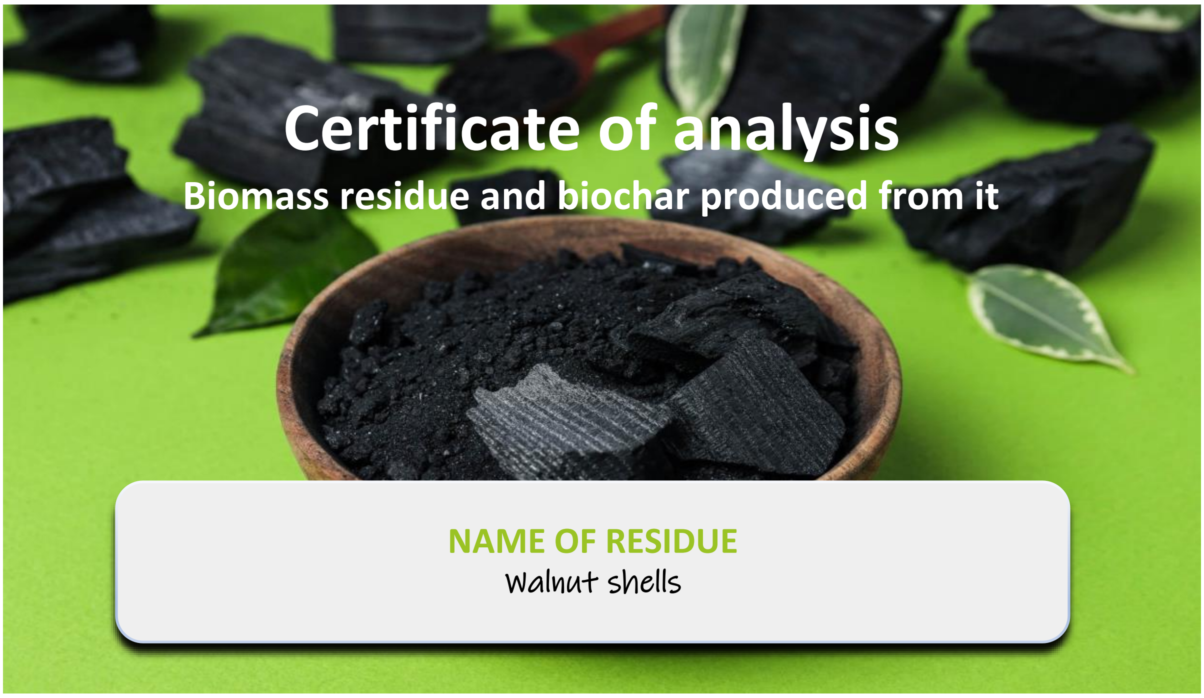
Parameter	Unit	Result	Method
Moisture content	w-%	3.96	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	w-% d.b	1.17	ISO 14820-2: 2016 CEN/TS 17773:2022
C	w-% d.b	84.97	Elementar analyser - Vario MACRO Cube, Elementar
H	w-% d.b	2.32	
N	w-% d.b	0.44	
S	w-% d.b	0.09	
O	w-% d.b	11.02	
HHV_{Milne}	MJ/kg	30.65	Milne's formula
LHV_{Milne}	MJ/kg	30.15	
Water holding capacity	g/g	3.9	ISO 14238: 2014 annex A
Residual at 105°C	%	98	ISO 14820-2:2016 CEN/TS 17773: 2022
Cation exchange capacity with $BaCl_2$	meq/100g	16.2	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	13	CEN/TS 17758: 2022
pH @ 24.6 °C	$-\log_{10}(c(H^+))$	6.941	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	2.0	
Phosphorus	P	mg/kg d.b.	48.4	
Manganese	Mn	mg/kg d.b.	112.0	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	
Nickel	Ni	mg/kg d.b.	2.1	
Lead	Pb	mg/kg d.b.	0.7	
Potassium	K	mg/kg d.b.	81.4	
Copper	Cu	mg/kg d.b.	3.5	
Thallium	Tl	mg/kg d.b.	< 0.5	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	8.5	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kgd.b.	< 0.01	CEN/TS 1618: 2018
Acenaphthylene	mg/kgd.b< 0.01.	< 0.01	
Anthracene	mg/kgd.b.	< 0.01	
Benzo(a)anthracene	mg/kgd.b.	< 0.01	
Benzo(a)pyrene	mg/kgd.b.	< 0.01	
Benzo(b)fluoranthene	mg/kgd.b.	< 0.01	
Benzo(ghi)perylene	mg/kgd.b.	< 0.01	
Benzo(k)fluoranthene	mg/kgd.b.	< 0.01	
Chrysene	mg/kgd.b.	< 0.01	
Dibenzo(a,h)anthracene	mg/kgd.b.	< 0.01	
Phenanthrene	mg/kgd.b.	< 0.01	
Fluoranthene	mg/kgd.b.	< 0.01	
Fluorene	mg/kgd.b.	< 0.01	
Indeno(1,2,3-cd)pyrene	mg/kgd.b.	< 0.01	
Naphthalene	mg/kgd.b.	0.10	
Pyrene	mg/kgd.b.	< 0.01	
Total EPA-PAH (by calculation)	mg/kgd.b.	0.10	
Total EFSA-PAH (by calculation)	mg/kgd.b.	< 0.01	



1 Introduction

Alps4GreenC aims at implementing transnational value-chains in the Alpine territories to facilitate the development and implementation of bio-economy focusing mainly on the sustainable production and utilization of green carbon especially, biochar. In the course of the activity 1.3 - Practical testing and pilot production of green carbon a certificate of analysis was prepared. This certificate presents the biomass residue analysis results, the biomass conversion technology adopted, and the biochar analysis results. The biomass residues were kindly provided by the participants in the crowdsourcing campaign.
The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sustainable Technologies GmbH (BEST) and gasification Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

This project is co-funded by the European Union through the Interreg Alpine Space programme

2 Description of the biomass residue walnut shells

The ***walnut shells*** (Figure 1) are produced during the nut cracking process and were provided by the company Nussland GmbH.

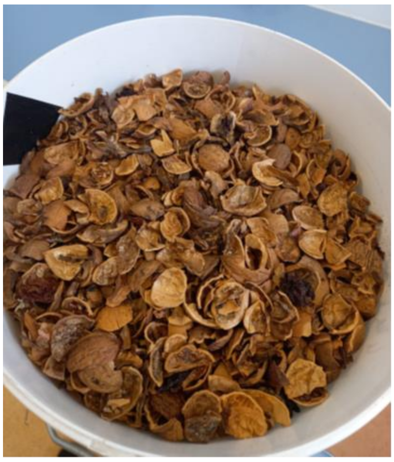


Figure 1: The walnut shells, photo credits: BEST

The walnut shells were analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;
General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value and bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	11.78 ±0.61	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	1.23 ±0.15	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	286 ±17	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	4.9 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	4.6 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	49.0	ISO16948 2015
Chlorine	w-% $_{d.b.}$	0.04 ±0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	5.9	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	43.4	calculated - by difference
Nitrogen	w-% $_{d.b.}$	0.4 ±0.1	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.03 ±0.01	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2	
Total chromium	Cr	w-% d.b.	1.8 ±0.5	
Manganese	Mn	w-% d.b.	7.0 ±1.2	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	1.2 ±0.4	
Lead	Pb	w-% d.b.	< 0.2	
Copper	Cu	w-% d.b.	3.4 ±0.9	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	5.0 ±0.9	
Phosphorus	P	w-% d.b.	305.8 ±51.7	
Potassium	K	w-% d.b.	2696.3 ±455.7	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	1.62	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	17.01	
Fraction 16 - 31.5 mm	w-%	80.11	
Fraction 31.5 - 45 mm	w-%	0.92	
Fraction 45 - 63 mm	w-%	0	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	0	
Sum in %	%	99.66	

3 Biochar production

The production of biochar from walnut shells was performed using thermochemical technology **pyrolysis** in lab-scale and pilotscale.

<u>The experimental setup</u>

The lab-scale pyrolysis (Figure 2) was performed on a rotary kiln, located at BEST in Wieselburg, Lower Austria.

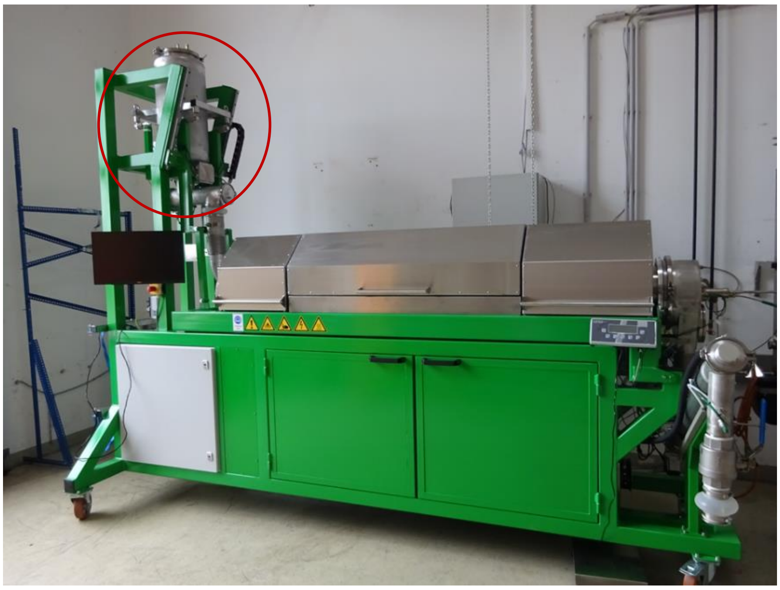


Figure 2: The used rotary kiln system, with the feedstock storage marked in red.

<u>The experimental setup of the pilotscale plant</u>

The pilot-scale pyrolysis test was conducted using a dual auger pyrolysis plant (Figure 3) made by REW Regenis. The plant is installed at our research facility in Wieselburg, Austria and has a nominal capacity of 20 kg/h biochar output.

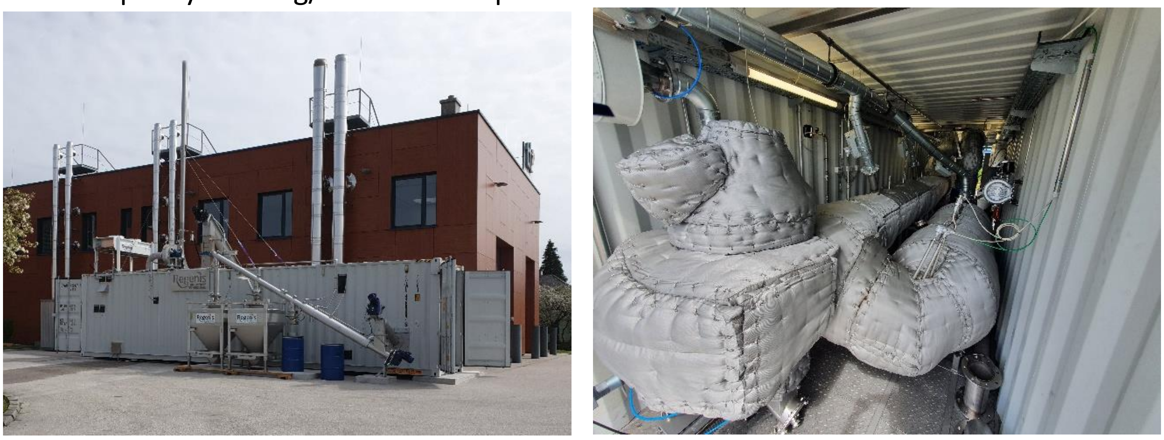


Figure 3: left: Pilot Scale pyrolysis plant from outside; right: pyrolysis plant inside container, pyrolysis reactor on left and gas burner on right side

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab srl. Biochar characterizations performed at Water & Life Lab srl were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, moisture content, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to Table 8.

Table 4: Biochar characterisation results

Parameter	**Unit**	**Result**	**Result**	**Method**
		Walnut shells lab-scale	Walnut shells pilotscale	
Moisture content	%wt	12.82	0.66	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	$\%wt_{dry}$	3.75	3.51	ISO 14820-2: 2016 CEN/TS 17773:2022
C	$\%wt_{dry}$	81.90	85.10	Elementar analyser - Vario MACRO Cube
H	$\%wt_{dry}$	2.80	3.19	
N	$\%wt_{dry}$	1.16	0.86	
S	$\%wt_{dry}$	0.25	0.33	
O	$\%wt_{dry}$	10.14	7.01	
HHV_{Milne}	MJ/kg	30.24	32.26	Milne's formula
LHV_{Milne}	MJ/kg	29.63	31.56	
Water holding capacity	g/g	1.9	2.0	ISO 14238: 2014 annex A
Residual at 105°C	%	87	99	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	13	1	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	13.9	17.6	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	299	305	CEN/TS 17758: 2022
pH @ 24.7 °C	$-\log_{10}(c(H^+))$	6.149	8.319	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Result	Method
			Walnut shells lab-scale	Walnut shells pilotscale	ISO 54321: 2021 Met B ISO 16170: 2016
Arsenic	As	mg/kg d.b.	< 1.0	< 1.0	
Cadmium	Cd	mg/kg d.b.	< 0.5	< 0.5	
Total chromium	Cr	mg/kg d.b.	6.3	4.8	
Phosphorus	P	mg/kg d.b.	810.6	531.5	
Manganese	Mn	mg/kg d.b.	16.4	9.0	
Mercury	Hg	mg/kg d.b.	< 0.01	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	< 0.5	
Nickel	Ni	mg/kg d.b.	3.9	2.9	
Lead	Pb	mg/kg d.b.	< 0.5	< 0.5	
Potassium	K	mg/kg d.b.	8 810.4	6 774.1	
Copper	Cu	mg/kg d.b.	6.1	5.6	
Thallium	Tl	mg/kg d.b.	< 1	< 1	
Vanadium	V	mg/kg d.b.	< 2.5	< 2.5	
Zinc	Zn	mg/kg d.b.	10.4	7.5	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Result	Method
		Walnut shells lab-scale	Walnut shells pilotscale	CEN/TS 1618: 2018
Acenaphthene	mg/kgd.b.	0.32	< 0.01	
Acenaphthylene	mg/kgd.b.	0.06	< 0.01	
Anthracene	mg/kgd.b.	1.03	0.03	
Benzo(a)anthracene	mg/kgd.b.	0.14	0.05	
Benzo(a)pyrene	mg/kgd.b.	0.07	0.06	
Benzo(b)fluoranthene	mg/kgd.b.	0.04	0.11	
Benzo(ghi)perylene	mg/kgd.b.	0.03	0.08	
Benzo(k)fluoranthene	mg/kgd.b.	0.02	0.11	
Chrysene	mg/kgd.b.	0.24	0.08	
Dibenzo(a.h)anthracene	mg/kgd.b.	0.02	0.07	
Phenanthrene	mg/kgd.b.	3.62	< 0.01	
Fluoranthene	mg/kgd.b.	0.50	< 0.01	
Fluorene	mg/kgd.b.	2.31	< 0.01	
Indeno(1.2.3-cd)pyrene	mg/kgd.b.	0.01	0.07	
Naphthalene	mg/kgd.b.	< 0.01	0.51	
Pyrene	mg/kgd.b.	0.59	< 0.01	
Total EPA-PAH (by calculation)	mg/kgd.b.	9.09	3.30	
Total EFSA-PAH (by calculation)	mg/kgd.b.	0.6	0.6	

Table 7: Results of the poly chlorinated diphenyls (PCB) measurements from the pilotscale walnut shells biochar

PCB	Unit	Result	Method
PCB 28 (TriCB)	mg/kg	< 0.01	EPA 3550 C 2007 EPA 8270 E 2018
PCB 52 (TetraCB)	mg/kg	< 0.01	
PCB 77 (TetraCB)	mg/kg	< 0.01	
PCB 81 (TetraCB)	mg/kg	< 0.01	
PCB 91 (TetraCB)	mg/kg	< 0.01	
PCB 99 (PentaCB)	mg/kg	< 0.01	
PCB 101 (PentaCB)	mg/kg	< 0.01	
PCB 105 (PentaCB)	mg/kg	< 0.01	
PCB 110 (PentaCB)	mg/kg	< 0.01	
PCB 114 (PentaCB)	mg/kg	< 0.01	
PCB 128+123 (PentaCB)	mg/kg	< 0.01	
PCB 126 (PentaCB)	mg/kg	< 0.01	
PCB 128 (HexaCB)	mg/kg	< 0.01	
PCB 138 (HexaCB)	mg/kg	< 0.01	
PCB 146 (HexaCB)	mg/kg	< 0.01	
PCB 149 (HexaCB)	mg/kg	< 0.01	
PCB 151 (HexaCB)	mg/kg	< 0.01	
PCB 153 (HexaCB)	mg/kg	< 0.01	
PCB 156 (HexaCB)	mg/kg	< 0.01	
PCB 157 (HexaCB)	mg/kg	< 0.01	
PCB 167 (HexaCB)	mg/kg	< 0.01	
PCB 169 (HexaCB)	mg/kg	< 0.01	
PCB 170 (HeptaCB)	mg/kg	< 0.01	
PCB 177 (HeptaCB)	mg/kg	< 0.01	
PCB 180 (HeptaCB)	mg/kg	< 0.01	
PCB 183 (HeptaCB)	mg/kg	< 0.01	
PCB 187 (HeptaCB)	mg/kg	< 0.01	
PCB 189 (HeptaCB)	mg/kg	< 0.01	
PCB sums (D.Lgs. n. 121 del 03/09/2020) mg/kg < 0.01	mg/kg	< 0.01	
PCB sums (Reg. CE 2019/1021 e s.m.i.)	mg/kg	< 0.01	

Table 8: Results of the dioxins and furans measurements

DIOXINS AND FURANS	Unit	Result	Method
PCDD:			EPA 8280 B 2007
2,3,7,8 TCDD	µg/kg	< 0.0010	
1,2,3,7,8 PCDD	µg/kg	< 0.0050	
1,2,3,4,7,8 HxCDD	µg/kg	< 0.0050	
1,2,3,7,8,9 HxCDD	µg/kg	< 0.0050	
1,2,3,6,7,8 HxCDD	µg/kg	< 0.0050	
1,2,3,4,6,7,8 HpCDD	µg/kg	< 0.0050	
OCDD	µg/kg	< 0.0100	
PCDF:			
2,3,7,8 TCDF	µg/kg	< 0.0010	
2,3,4,7,8 PCDF	µg/kg	< 0.0050	
1,2,3,7,8 PCDF	µg/kg	< 0.0050	
1,2,3,4,7,8 HxCDF	µg/kg	< 0.0050	
1,2,3,7,8,9 HxCDF	µg/kg	< 0.0050	
1,2,3,6,7,8 HxCDF	µg/kg	< 0.0050	
2,3,4,6,7,8 HxCDF	µg/kg	< 0.0050	
1,2,3,4,6,7,8 HpCDF	µg/kg	< 0.0050	
1,2,3,4,7,8,9 HpCDF	µg/kg	< 0.0050	
OCDF	µg/kg	< 0.0100	
Sum of PCDD/PCDF	µg/kg	0.0057	

5 Discussion

The produced biochars show very promising properties for applications in both steel industry and agriculture. They have very high heating values and carbon contents and low ash contents at the same time, which all are desired properties by the steel industry (ISBN 978-3-658-03688-1). Regarding the agricultural application, the biochars show low levels in heavy metals and considerable levels in the nutrient elements phosphorous and potassium. Compared to the lab-scale biochar, the pilot-scale biochar also shows a high pH which could be desired for acidic soils (DOI: 10.1111/gcbb.12889) and it has the higher cation exchange capacity of the two biochars. The pilot-scale biochar also shows considerably less PAH pollutants and it showed none of the other organic pollutants it was analysed for. In conclusion, while both produced biochars show very promising properties for the application in steel industry and agriculture only the pilot-scale biochar could be used as is for future studies. For further investigations with the lab-scale equipment a change in process conditions would be required to lower the PAH pollutants, moisture content and other effects of the liquid-condensation during the process.

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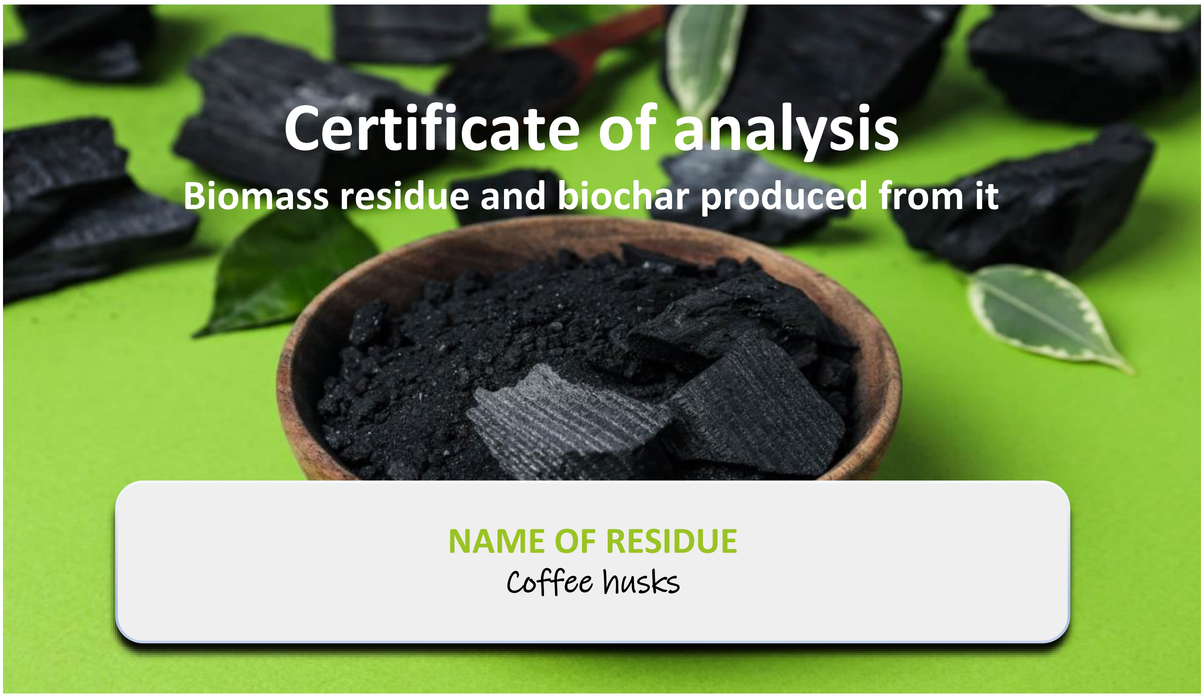

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The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

2 Description of the biomass residue - Coffee husks

The ***coffee husks*** (Figure 1) residue came from the roasting process of coffee and was provided by the company Barcaffe in Izola.

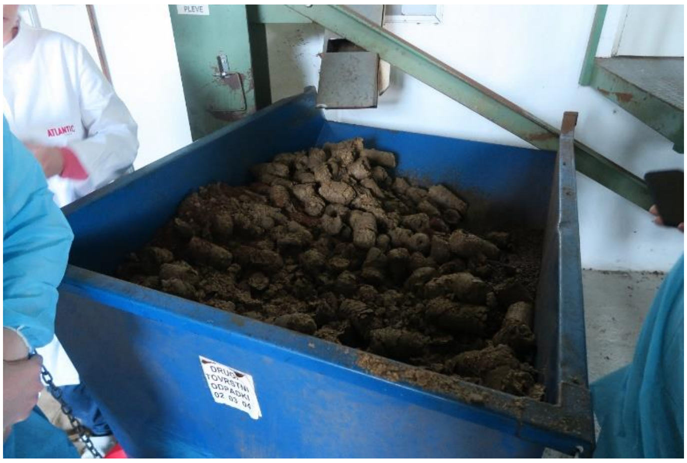

Figure 1: The coffee husks, photo credits: CCIS, Slovenia

The coffee husks were analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis.
General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density and ash melting behavior. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	25.04 ±1.30	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	7.32 ±0.90	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	342 ±20	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	3.9 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	3.6 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	46.7	ISO16948 2015
Chlorine	w-% $_{d.b.}$	0.06 ±0.02	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	6.1	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	36.6	calculated - by difference
Nitrogen	w-% $_{d.b.}$	2.9 ±0.4	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.28 ±0.09	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Uncertainty	Method
Arsenic	As	w-% d.b.	< 0.4		ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2		
Total chromium	Cr	w-% d.b.	1.8	±0.5	
Manganese	Mn	w-% d.b.	44.0	±7.4	
Mercury	Hg	w-% d.b.	< 0.04		
Nickel	Ni	w-% d.b.	1.0	±0.3	
Lead	Pb	w-% d.b.	0.3	±0.1	
Copper	Cu	w-% d.b.	63.6	±17.7	
Thallium	Tl	w-% d.b.	< 2.0		
Zinc	Zn	w-% d.b.	15.2	±2.6	
Phosphorus	P	w-% d.b.	918.0	±155.1	
Potassium	K	w-% d.b.	16747.2	±2830.3	

Table 3: Particle size analysis

Particle size	Unit	Result	Uncertainty	Method
Fraction < 3.15 mm	w-%	12.88	±0.64	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	85.92	±4.30	
Fraction 16 - 31.5 mm	w-%	85.92	±4.30	
Fraction 31.5 - 45 mm	w-%	85.92	±4.30	
Fraction 45 - 63 mm	w-%	85.92	±4.30	
Fraction 63 - 100 mm	w-%	< 1		
Fraction > 100 mm	w-%	< 1		
Sum in %	%	< 1		
Coarse fraction over 31.5 mm	w-%	< 1		ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	< 45		
Coarse fraction over 63 mm	w-%	< 0.50		
Coarse fraction over 100 mm	w-%	12.88	±0.64	
Max length of particles	w-%	85.92	±4.30	
Largest cross sectional area	cm^2	85.92	±4.30	

This project is co-funded by the European Union through the Interreg Alpine Space programme

3 Biochar production

The production of biochar from coffee husks was produiced using thermochemical technology called **pyrolysis.**

The experimental setup

The lab-scale pyrolysis (**Error! Reference source not found.**) was performed on a rotary kiln, located at BEST in Wieselburg, Lower Austria.

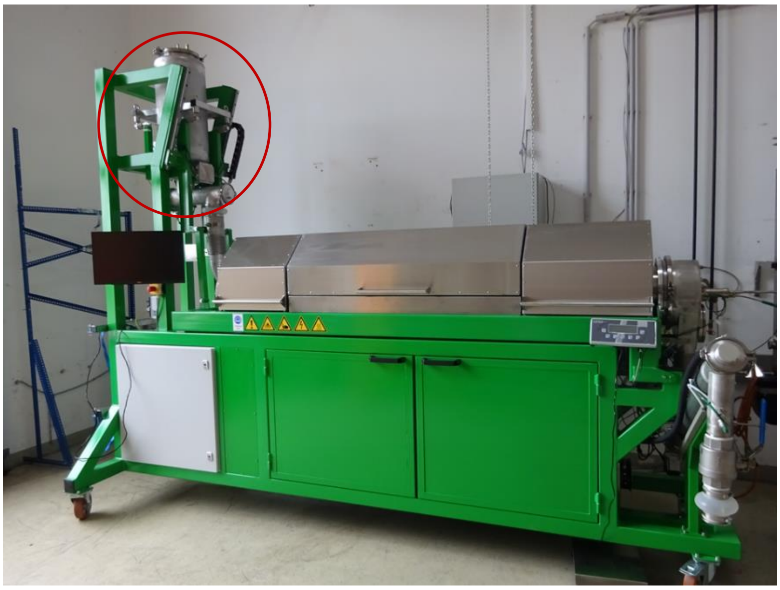

Figure 2: The used rotary kiln system, with the feedstock storage marked in red.

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab srl. Biochar characterizations performed at Water & Life Lab srl were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, moisture content, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 1 to **Error! Reference source not found.**.

Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	**%wt**	12.29	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	**$\%wt_{dry}$**	20.19	ISO 14820-2: 2016 CEN/TS 17773:2022
C	**$\%wt_{dry}$**	63.36	Elementar analyser - Vario MACRO Cube, Elementar
H	**$\%wt_{dry}$**	3.31	
N	**$\%wt_{dry}$**	3.62	
S	**$\%wt_{dry}$**	0.55	
O	**$\%wt_{dry}$**	8.97	
HHV_{Milne}	**MJ/kg**	24.20	Milne’s formula
LHV_{Milne}	**MJ/kg**	23.48	
Water holding capacity	g/g	3.8	ISO 14238: 2014 annex A
Residual at 105°C	%	89	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	11	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	24.5	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	1149	CEN/TS 17758: 2022
pH @ 24,2 °C	$-\log_{10}(c(H^+))$	9.692	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	8.7	
Phosphorus	P	mg/kg d.b.	1 863.2	
Manganese	Mn	mg/kg d.b.	127.2	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	
Nickel	Ni	mg/kg d.b.	6.0	
Lead	Pb	mg/kg d.b.	< 0.5	
Potassium	K	mg/kg d.b.	43193.7	
Copper	Cu	mg/kg d.b.	136.0	
Thallium	Tl	mg/kg d.b.	< 1	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	44.5	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kgd.b.	0.50	CEN/TS 1618: 2018
Acenaphthylene	mg/kgd.b.	0.12	
Anthracene	mg/kgd.b.	0.51	
Benzo(a)anthracene	mg/kgd.b.	0.23	
Benzo(a)pyrene	mg/kgd.b.	0.11	
Benzo(b)fluoranthene	mg/kgd.b.	0.04	
Benzo(ghi)perylene	mg/kgd.b.	0.03	
Benzo(k)fluoranthene	mg/kgd.b.	0.04	
Chrysene	mg/kgd.b.	0.36	
Dibenzo(a,h)anthracene	mg/kgd.b.	0.03	
Phenanthrene	mg/kgd.b.	4.20	
Fluoranthene	mg/kgd.b.	0.54	
Fluorene	mg/kgd.b.	1.95	
Indeno(1,2,3-cd)pyrene	mg/kgd.b.	0.01	
Naphthalene	mg/kgd.b.	0.02	
Pyrene	mg/kgd.b.	0.71	
Total EPA-PAH (by calculation)	mg/kgd.b.	9.55	
Total EFSA-PAH (by calculation)	mg/kgd.b.	0.9	

5 Discussion

The produced biochar from coffee husks could unfortunately not be used as animal feed or in agricultural use as soil amendment because it has too high copper content and PAH content (https://www.european-biochar.org/media/doc/2/version_en_10_1.pdf). Also, the low fixed carbon content and low calorific value make it not applicable to the steel industry as a substitution of coal-based fuels (https://www.sciencedirect.com/science/article/pii/S0016236123000145). However, this biochar could be used in some other applications e.g. for artistic drawing with charcoal.

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Certificate of analysis

Biomass residue and biochar produced from it

NAME OF RESIDUE
River woody debris

1 Introduction

Alps4GreenC aims at implementing transnational value-chains in the Alpine territories to facilitate the development and implementation of bio-economy focusing mainly on the sustainable production and utilization of green carbon especially, biochar. In the course of the activity 1.3 - Practical testing and pilot production of green carbon a certificate of analysis was prepared. This certificate presents the biomass residue analysis results, the biomass conversion technology adopted, and the biochar analysis results. The biomass residues were kindly provided by the participants in the crowdsourcing campaign.
The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

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2 Description of the biomass residue - River woody debris

The ***river woody debris*** (Figure 1) came from the company Dravske elektrarne Maribor, d.o.o., which produces almost a quarter of the total electricity produced in Slovenia.

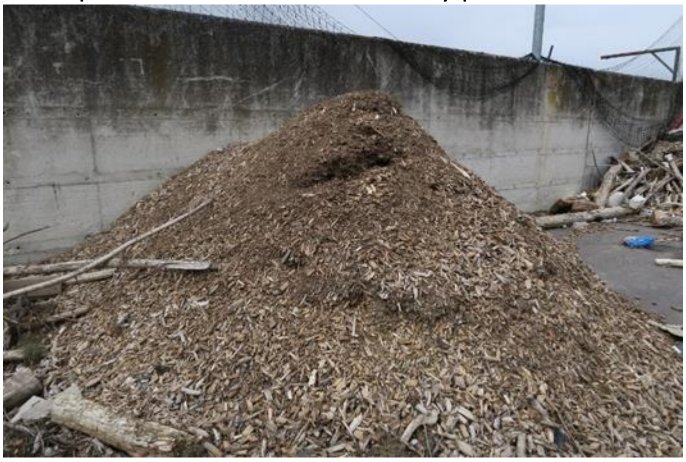

Figure 1: Wood debris at the hydroelectric plant at Zlatoličje, Slovenia

The river woody debris were analyzed by the *Water & Life Lab srL, Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis.

General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density and ash melting behavior. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	26.27 ±1.37	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	1.70 ±0.21	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	217 ±13	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	3.9 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	3.6 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	47.6	ISO16948 2015
Chlorine	w-% $_{d.b.}$	< 0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	6	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	44.4	calculated - by difference
Nitrogen	w-% $_{d.b.}$	0.3 ±0.1	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.04 ±0.02	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Uncertainty	Method
Arsenic	As	w-% d.b.	< 0.4		ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	0.2	±0.1	
Total chromium	Cr	w-% d.b.	6.4	±1.6	
Manganese	Mn	w-% d.b.	74.9	±12.7	
Mercury	Hg	w-% d.b.	< 0.04		
Nickel	Ni	w-% d.b.	3.2	±0.9	
Lead	Pb	w-% d.b.	1.9	±0.5	
Copper	Cu	w-% d.b.	3.1	±0.9	
Thallium	Tl	w-% d.b.	< 2.0		
Zinc	Zn	w-% d.b.	21.0	±3.6	
Phosphorus	P	w-% d.b.	171.3	±29.0	
Potassium	K	w-% d.b.	615.6	±104.0	

Table 3: Particle size analysis

Particle size	Unit	Result	Uncertainty	Method
Fraction < 3.15 mm	w-%	2.88	±0.14	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	24.76	±1.24	
Fraction 16 - 31.5 mm	w-%	63.47	±3.17	
Fraction 31.5 - 45 mm	w-%	82.01	±4.10	
Fraction 45 - 63 mm	w-%	87.21	±4.36	
Fraction 63 - 100 mm	w-%	18.76	±0.94	
Fraction > 100 mm	w-%	5.26	±0.26	
Sum in %	%	< 1		
Coarse fraction over 31.5 mm	w-%	8.73	±0.44	ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	< 45		
Coarse fraction over 63 mm	w-%	11		
Coarse fraction over 100 mm	w-%	2.88	±0.14	
Max length of particles	w-%	24.76	±1.24	
Largest cross sectional area	cm^2	63.47	±3.17	

3 Biochar production

The production of biochar from river woody debris was produced using thermochemical technology called **gasification**.

<u>The experimental setup</u>

The experiments on a lab-scale gasifier (Figure) were conducted on a reverse updraft batch reactor at the Free University of Bozen-Bolzano, Italy.

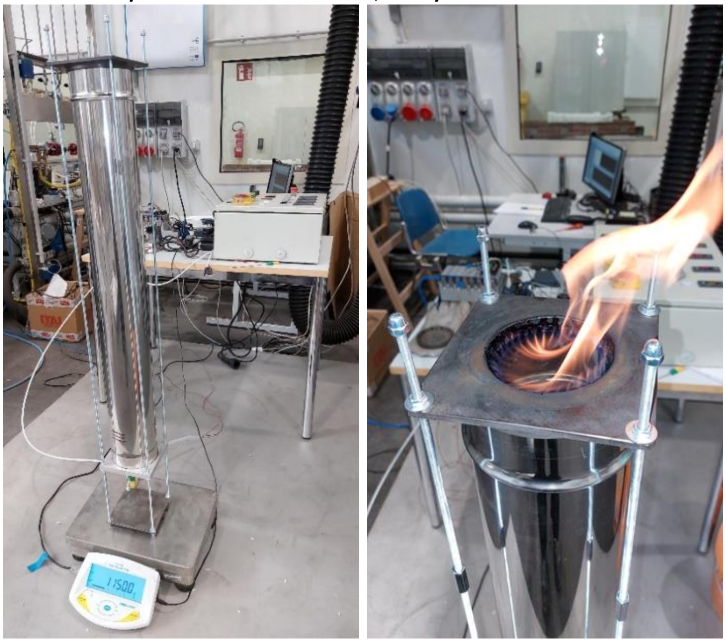

Figure 2: Lab-scale gasifier – mounted on weighing scale (L), during operation (R)

4 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab srl. Biochar characterizations performed at Water & Life Lab srl were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, moisture content, cation exchange capacity, chlorides, PAH, PCB, Dioxins and furans. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 1 to **Error! Reference source not found.**.

Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	**%wt**	2.95	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	**$\%wt_{dry}$**	4.25	ISO 14820-2: 2016 CEN/TS 17773:2022
C	**$\%wt_{dry}$**	76.92	Elementar analyser - Vario MACRO Cube, Elementar
H	**$\%wt_{dry}$**	3.19	
N	**$\%wt_{dry}$**	0.69	
S	**$\%wt_{dry}$**	0.10	
O	**$\%wt_{dry}$**	14.86	
HHV_{Milne}	**MJ/kg**	28.52	Milne's formula
LHV_{Milne}	**MJ/kg**	27.83	
Water holding capacity	g/g	4.8	ISO 14238: 2014 annex A
Residual at 105°C	%	99	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	1	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	25.0	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	43	CEN/TS 17758: 2022
pH @22,6 °C	$-\log_{10}(c(H^+))$	7.796	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	0.6	
Total chromium	Cr	mg/kg d.b.	65.7	
Phosphorus	P	mg/kg d.b.	587.1	
Manganese	Mn	mg/kg d.b.	201.6	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	
Nickel	Ni	mg/kg d.b.	3.1	
Lead	Pb	mg/kg d.b.	5.1	
Potassium	K	mg/kg d.b.	1010.9	
Copper	Cu	mg/kg d.b.	46.6	
Thallium	Tl	mg/kg d.b.	< 0.5	
Vanadium	V	mg/kg d.b.	3.2	
Zinc	Zn	mg/kg d.b.	68.9	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kg d.b.	< 0.01	CEN/TS 1618: 2018
Acenaphthylene	mg/kg d.b.	< 0.01	
Anthracene	mg/kg d.b.	< 0.01	
Benzo(a)anthracene	mg/kg d.b.	< 0.01	
Benzo(a)pyrene	mg/kg d.b.	< 0.01	
Benzo(b)fluoranthene	mg/kg d.b.	< 0.01	
Benzo(ghi)perylene	mg/kg d.b.	< 0.01	
Benzo(k)fluoranthene	mg/kg d.b.	< 0.01	
Chrysene	mg/kg d.b.	< 0.01	
Dibenzo(a,h)anthracene	mg/kg d.b.	< 0.01	
Phenanthrene	mg/kg d.b.	0.04	
Fluoranthene	mg/kg d.b.	< 0.01	
Fluorene	mg/kg d.b.	< 0.01	
Indeno(1,2,3-cd)pyrene	mg/kg d.b.	< 0.01	
Naphthalene	mg/kg d.b.	0.11	
Pyrene	mg/kg d.b.	< 0.01	
Total EPA-PAH (by calculation)	mg/kg d.b.	0.14	
Total EFSA-PAH (by calculation)	mg/kg d.b.	<0.01	

5 Discussion

The produced biochar from river woody debris could be used as animal feed or in agricultural use as soil amendment (https://www.european-biochar.org/media/doc/2/version_en_10_1.pdf). Also, based on its values of fixed carbon content and calorific value it would also be appropriate to use in the steel industry as a substitution of coal-based fuels (https://www.sciencedirect.com/science/article/pii/S0016236123000145).

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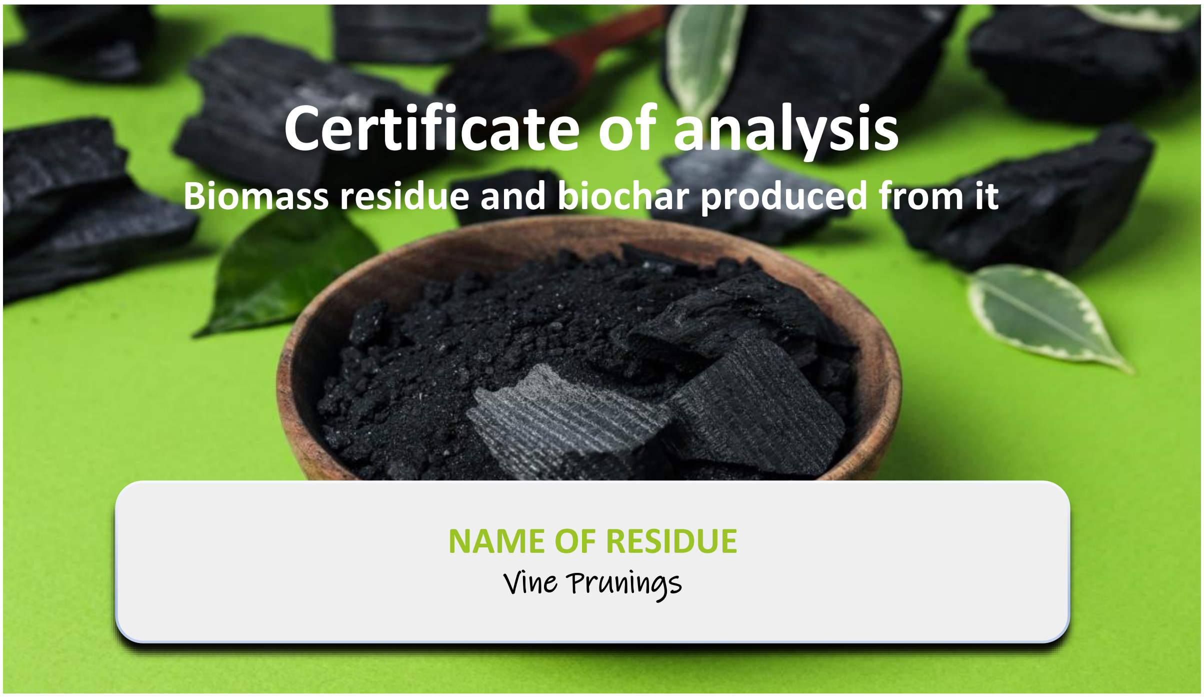

1 Introduction

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The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification at the Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

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Description of the biomass residue: Vine Prunings

The ***Vine Prunings*** (Figure 1) come from grape harvesting process and were provided by the company Az. Agr. Corte Arano di Giovannini Mattia in Italy.

Figure 1: Vine prunings

The vine prunings were analyzed by the *Water & Life Lab S.r.l., Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;
General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	13.10 ±0.68	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	3.61 ±0.44	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	107 ±6	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	4.5 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	4.2 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	46.4	ISO16948 2015
Chlorine	w-% $_{d.b.}$	0.02 ±0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	6.0	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	43.1	calculated - by difference
Nitrogen	w-% $_{d.b.}$	0.8 ±0.2	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.07 ±0.02	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	< 0.2	
Total chromium	Cr	w-% d.b.	3.8 ±1.0	
Manganese	Mn	w-% d.b.	34.5 ±5.8	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	2.4 ±0.7	
Lead	Pb	w-% d.b.	0.5 ±0	
Copper	Cu	w-% d.b.	11.7 ±3.3	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	37.3 ±6.3	
Phosphorus	P	w-% d.b.	1105.0 ±186.8	
Potassium	K	w-% d.b.	5685.1 ±960.8	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	1.27	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	11.38	
Fraction 16 - 31.5 mm	w-%	7.46	
Fraction 31.5 - 45 mm	w-%	4.88	
Fraction 45 - 63 mm	w-%	1.31	
Fraction 63 - 100 mm	w-%	22.14	
Fraction > 100 mm	w-%	51.46	
Sum in %	%	99.9	
Coarse fraction over 31.5 mm	w-%	79.79	ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	74.91	
Coarse fraction over 63 mm	w-%	73.6	
Coarse fraction over 100 mm	w-%	51.46	

2 Biochar production

The production of biochar from vine prunings was performed using gasification technology.

The experimental setup

The experiments on a lab-scale gasifier (Figure Figure 2) were conducted on a reverse updraft batch reactor at the Free University of Bozen-Bolzano, Italy.

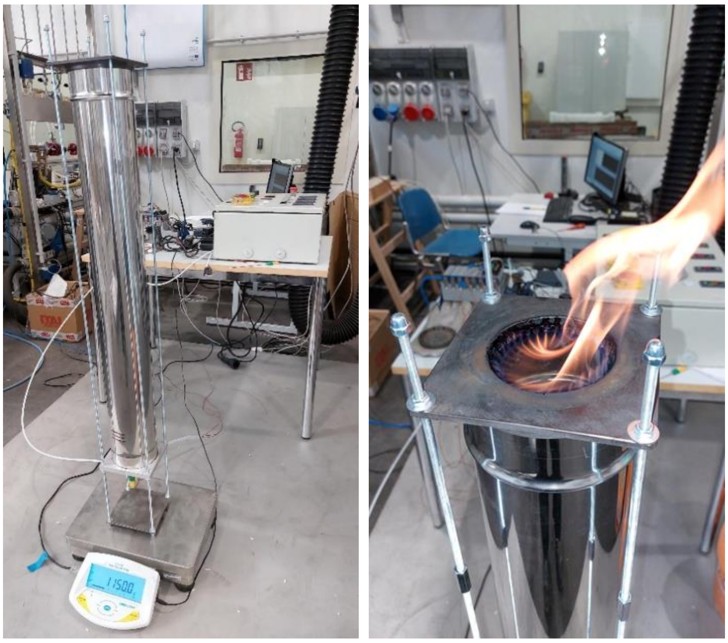

Figure 2: Lab-scale gasifier – mounted on weighing scale (L), during operation (R)

The biochar produced is shown in Figure 3.

Figure 3: Biochar produced from gasification of vine prunings

3 Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab S.r.l.. Biochar characterizations performed at Water & Life Lab S.r.l. were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, cation exchange capacity, chlorides, PAH. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to Table 6.

Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	w-%	4.08	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	w-% d.b	14.75	ISO 14820-2: 2016 CEN/TS 17773:2022
C	w-% d.b	81.51	Elementar analyser - Vario MACRO Cube, Elementar
H	w-% d.b	1.55	
N	w-% d.b	1.16	
S	w-% d.b	0.29	
O	w-% d.b	0.74	
HHV_{Milne}	MJ/kg	29.41	Milne's formula
LHV_{Milne}	MJ/kg	29.07	
Water holding capacity	g/g	3.4	ISO 14238: 2014 annex A
Residual at 105°C	%	97	ISO 14820-2:2016 CEN/TS 17773: 2022
Moisture content	%	3	ISO 14820-2:2016 CEN/TS 17773:2022
Cation exchange capacity with $BaCl_2$	meq/100g	19.0	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	219	CEN/TS 17758: 2022
pH @ 24.5 °C	$-\log_{10}(c(H^+))$	8.789	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	11.3	
Phosphorus	P	mg/kg d.b.	4 464.4	
Manganese	Mn	mg/kg d.b.	118.1	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	< 0.5	
Nickel	Ni	mg/kg d.b.	5.5	
Lead	Pb	mg/kg d.b.	< 0.5	
Potassium	K	mg/kg d.b.	21 511.8	
Copper	Cu	mg/kg d.b.	23.5	
Thallium	Tl	mg/kg d.b.	< 0.5	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	113.2	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	$mg/kg_{d.b.}$	< 0.01	CEN/TS 1618: 2018
Acenaphthylene	$mg/kg_{d.b< 0.01.}$	< 0.01	
Anthracene	$mg/kg_{d.b.}$	< 0.01	
Benzo(a)anthracene	$mg/kg_{d.b.}$	< 0.01	
Benzo(a)pyrene	$mg/kg_{d.b.}$	< 0.01	
Benzo(b)fluoranthene	$mg/kg_{d.b.}$	< 0.01	
Benzo(ghi)perylene	$mg/kg_{d.b.}$	< 0.01	
Benzo(k)fluoranthene	$mg/kg_{d.b.}$	< 0.01	
Chrysene	$mg/kg_{d.b.}$	< 0.01	
Dibenzo(a,h)anthracene	$mg/kg_{d.b.}$	< 0.01	
Phenanthrene	$mg/kg_{d.b.}$	< 0.01	
Fluoranthene	$mg/kg_{d.b.}$	< 0.01	
Fluorene	$mg/kg_{d.b.}$	< 0.01	
Indeno(1,2,3-cd)pyrene	$mg/kg_{d.b.}$	< 0.01	
Naphthalene	$mg/kg_{d.b.}$	< 0.01	
Pyrene	$mg/kg_{d.b.}$	< 0.01	
Total EPA-PAH (by calculation)	$mg/kg_{d.b.}$	< 0.01	
Total EFSA-PAH (by calculation)	$mg/kg_{d.b.}$	< 0.01	

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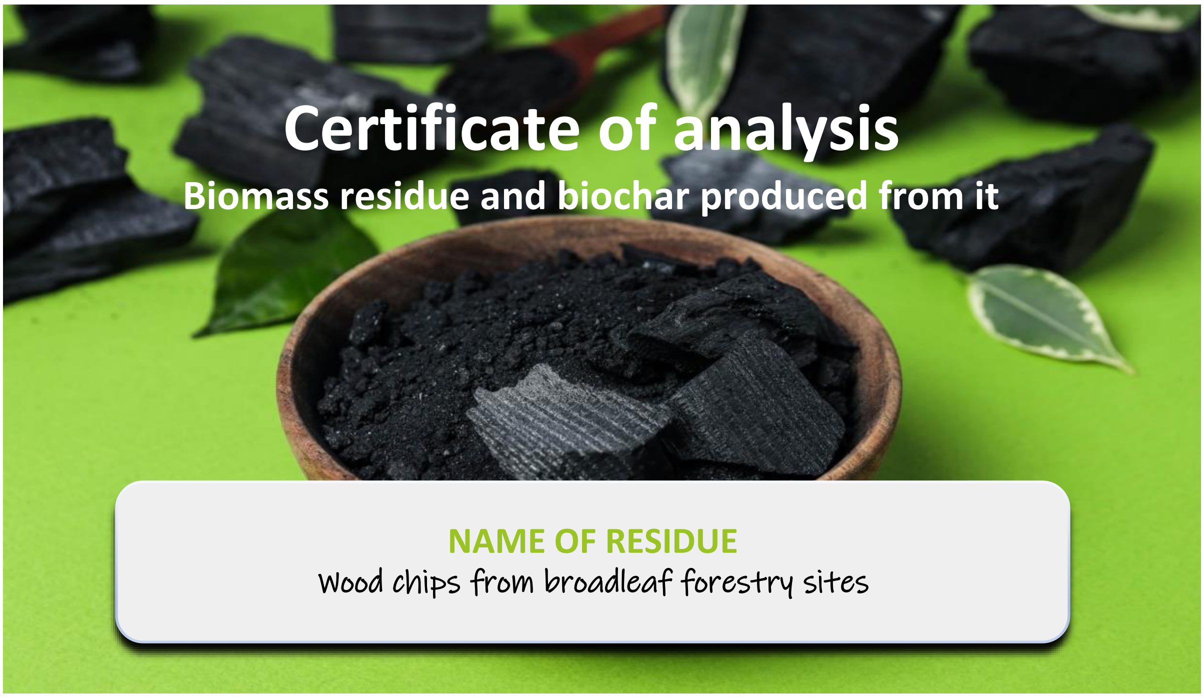

Certificate of analysis

Biomass residue and biochar produced from it

NAME OF RESIDUE

Wood chips from broadleaf forestry sites

Introduction

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The biomass residues were first analysed by Water&Life Lab, then converted into biochar via pyrolysis at BEST – Bioenergy and Sutstainable Technologies GmbH (BEST) and gasification at the Free University of Bozen-Bolzano (unibz), respectively. Subsequently, the produced biochars were analysed by National Institute of Chemistry (NIC), Water&Life Lab and unibz.

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Description of the biomass residue: Wood chips from broadleaf forestry sites

The ***wood chips (WC)*** (Figure 1) come from broadleaf forestry sites and were provided by the company Biomass Green Energy srl in Italy.

Figure 1: Wood chips from broadleaf forestry sites in Italy

The wood chips were analyzed by the *Water & Life Lab S.r.l., Via Enrico Mattei n°37, 24060 - Entratico (BG) – ITALY.* The analysis results can be summarized in three different groups, shown in Table 1 to Table 3: General residue characterization, Heavy metal and inorganic nutrient contents and Particle size analysis;

General residue characterization covers moisture content, ash and volatile matter content, elemental analysis for C/H/N/S/Cl, heating value, bulk density. Particle size analysis covers the particle size distribution of the biomass residues. Both general residue characterization and particle size distribution were necessary to determine the suitability of the residues as received or the need of a pretreatment step. Moreover, heavy metal and nutrient analysis were performed in order to evaluate, if any elements are influenced by the thermochemical conversion, either through emission or contamination.

Table 1: General residue characterisation

Paramter	Unit	Result	Method
Moisture content	w-% $_{d.b.}$	29.89 ±1.55	ISO 14780: 2019; ISO 18134-1: 2015
Ash content at 550°	w-% $_{d.b.}$	3.61 ±0.44	ISO 14780:2019; ISO 18122: 2016
Bulk density	kg/m^3	246 ±15	ISO 14780: 2019; ISO 17828:2016
Gross calorific value	kWh/kg	3.5 ±0.1	ISO 18125:2018
Net calorific value	kWh/kg	3.3 ±0.1	ISO 18125:2018
Carbon	w-% $_{d.b.}$	46.0	ISO16948 2015
Chlorine	w-% $_{d.b.}$	0.01 ±0.01	ISO 16994: 2017 Met; ISO 10304-1: 2009
Hydrogen	w-% $_{d.b.}$	6.0	ISO16948: 2015
Oxygen	w-% $_{d.b.}$	43.9	calculated - by difference
Nitrogen	w-% $_{d.b.}$	0.5	ISO16948: 2015
Sulphur	w-% $_{d.b.}$	0.05 ±0.02	ISO 16994: 2017 Met A; ISO 10304-1:2009

Table 2: Heavy metal and inorganic nutrient contents

Element	Symbol	Unit	Result	Method
Arsenic	As	w-% d.b.	< 0.4	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Cadmium	Cd	w-% d.b.	0.3 ±0.1	
Total chromium	Cr	w-% d.b.	2.8 ±0.7	
Manganese	Mn	w-% d.b.	15.6 ±2.6	
Mercury	Hg	w-% d.b.	< 0.04	
Nickel	Ni	w-% d.b.	1.4 ±0.4	
Lead	Pb	w-% d.b.	0.5 ±0.1	
Copper	Cu	w-% d.b.	5.8 ±1.6	
Thallium	Tl	w-% d.b.	< 2.0	
Zinc	Zn	w-% d.b.	29.4 ±5.0	
Phosphorus	P	w-% d.b.	540.1 ±91.3	
Potassium	K	w-% d.b.	2638.9 ±446.0	

Table 3: Particle size analysis

Particle size	Unit	Result	Method
Fraction < 3.15 mm	w-%	3.66	ISO 14780: 2019 ISO 16968:2015 ISO 6170: 2016
Fraction 3.15 - 16 mm	w-%	27.18	
Fraction 16 - 31.5 mm	w-%	50.42	
Fraction 31.5 - 45 mm	w-%	9.85	
Fraction 45 - 63 mm	w-%	1.95	
Fraction 63 - 100 mm	w-%	0	
Fraction > 100 mm	w-%	5.08	
Sum in %	%	98.14	
Coarse fraction over 31.5 mm	w-%	16.88	ISO 14780: 2019 ISO 17827-1: 2016
Coarse fraction over 45 mm	w-%	7.03	
Coarse fraction over 63 mm	w-%	5.08	
Coarse fraction over 100 mm	w-%	5.08	

Biochar production

The production of biochar from wood chips was performed pyrolysis.

The experimental setup

The lab-scale pyrolysis (Figure 2) was performed on a rotary kiln, located at BEST in Wieselburg, Lower Austria.

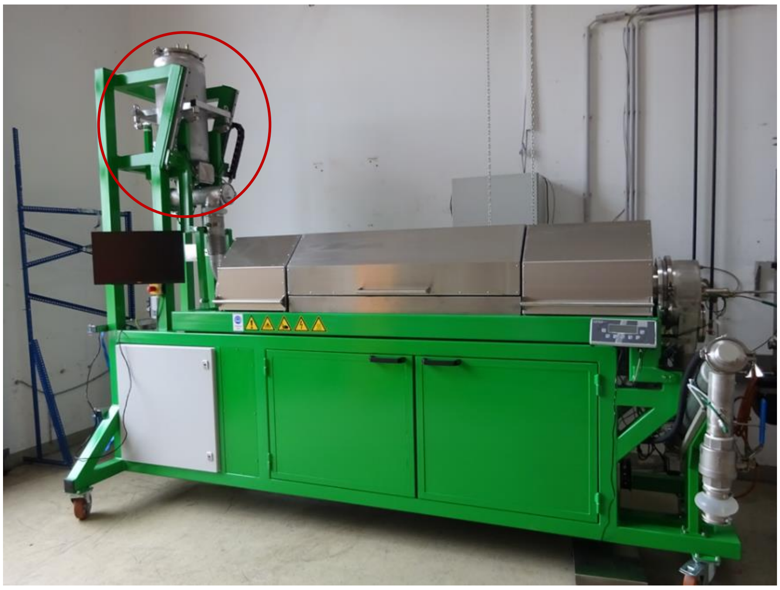

Figure 2: The used rotary kiln system, with the feedstock storage marked in red

The biochar produced is shown in Figure 3.

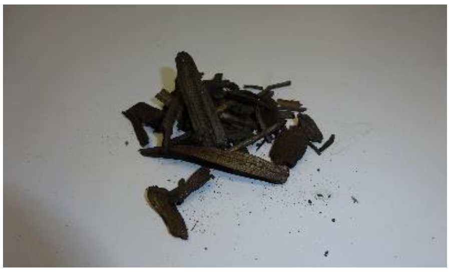

Figure 3: Biochar produced from pyrolysis of wood chips

Biochar characterization and results

The biochar samples were characterized at the National Institute of Chemistry (NIC), at the Free University of Bozen-Bolzano (unibz) and at the Water & Life Lab S.r.l.. Biochar characterizations performed at Water & Life Lab S.r.l. were: Heavy metal and inorganic nutrients, water holding capacity, residual at 105 °C, cation exchange capacity, chlorides, PAH. Biochar characterizations performed at unibz were: moisture content, ash content, C/H/N/S/O and heating value. Biochar characterizations performed at NIC were: pH measurements; The biochar analysis results are indicated in Table 4 to Table 6.

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Table 4: Biochar characterisation results

Parameter	Unit	Result	Method
Moisture content	w-%	29.89	ISO 14820-2: 2016 CEN/TS 17773: 2022
Ash content	w-% $_{d.b}$	3.61	ISO 14820-2: 2016 CEN/TS 17773:2022
C	w-% $_{d.b}$	46.0	Elementar analyser - Vario MACRO Cube, Elementar
H	w-% $_{d.b}$	6.0	
N	w-% $_{d.b}$	0.5	
S	w-% $_{d.b}$	0.05	
O	w-% $_{d.b}$	43.9	
HHV_{Milne}	MJ/kg	26.92	Milne's formula
LHV_{Milne}	MJ/kg	26.29	
Water holding capacity	g/g	2.4	ISO 14238: 2014 annex A
Residual at 105°C	%	92	ISO 14820-2:2016 CEN/TS 17773: 2022
Cation exchange capacity with $BaCl_2$	meq/100g	23.6	DM 13/09/99 GU248 21/10/1999 Met.XIII. DM 25/03/2002 GU84 10/04/2002
Chlorides	mg/kg d.b.	150	CEN/TS 17758: 2022
pH @ 24.5 °C	$-\log_{10}(c(H^+))$	6.865	*European Biochar Certificate (EBC)* guideline

Table 5: Heavy metal and inorganic nutrients of the biochar

Element	Symbol	Unit	Result	Method
Arsenic	As	mg/kg d.b.	< 1.0	ISO 54321: 2021 Met B ISO 16170: 2016
Cadmium	Cd	mg/kg d.b.	< 0.5	
Total chromium	Cr	mg/kg d.b.	6.4	
Phosphorus	P	mg/kg d.b.	1 782.6	
Manganese	Mn	mg/kg d.b.	40.1	
Mercury	Hg	mg/kg d.b.	< 0.01	
Molybdenum	Mo	mg/kg d.b.	0.7	
Nickel	Ni	mg/kg d.b.	3.8	
Lead	Pb	mg/kg d.b.	1.1	
Potassium	K	mg/kg d.b.	8 120.6	
Copper	Cu	mg/kg d.b.	15.8	
Thallium	Tl	mg/kg d.b.	< 1	
Vanadium	V	mg/kg d.b.	< 2.5	
Zinc	Zn	mg/kg d.b.	90.0	

Table 6: Results of the polycyclic aromatic hydrocarbons (PAHs) measurements

PAH	Unit	Result	Method
Acenaphthene	mg/kg d.b.	0.11	CEN/TS 1618: 2018
Acenaphthylene	mg/kg d.b.	0.08	
Anthracene	mg/kg d.b.	0.37	
Benzo(a)anthracene	mg/kg d.b.	0.05	
Benzo(a)pyrene	mg/kg d.b.	0.03	
Benzo(b)fluoranthene	mg/kg d.b.	0.02	
Benzo(ghi)perylene	mg/kg d.b.	0.02	
Benzo(k)fluoranthene	mg/kg d.b.	0.01	
Chrysene	mg/kg d.b.	0.07	
Dibenzo(a,h)anthracene	mg/kg d.b.	0.01	
Phenanthrene	mg/kg d.b.	1.22	
Fluoranthene	mg/kg d.b.	0.21	
Fluorene	mg/kg d.b.	0.79	
Indeno(1,2,3-cd)pyrene	mg/kg d.b.	< 0.01	
Naphthalene	mg/kg d.b.	0.01	
Pyrene	mg/kg d.b.	0.26	
Total EPA-PAH (by calculation)	mg/kg d.b.	3.30	
Total EFSA-PAH (by calculation)	mg/kg d.b.	0.2	