Life Cycle Assessment

of

Biochar from grain husks and wood screening residue

By

Sonnenerde GmbH

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SONNENERDE

VästLCA
Data-driven Sustainability

Executive summary for CORCs issuance

1 ton of biochar (DM) that is applied to fields in Austria produced by Sonnenerde in Riedlingsdorf through pyrolysis of grain husks from grain cleaning of sunflowers, and wood screening residue from the Sonnenerde composting plant, has a carbon sequestration potential of **1 875 kg CO2,eq** over 100 years.

This equals **1,88 CORCs**, meaning that **1 CORC** requires **532 kg biochar (DM)**

1 ton of biochar (DM) needs 249 kg of grain husks (wet weight, 5% moisture content) and 2 505 kg of wood screening residue (wet weight, 5% moisture)

General overview of the project

This study has been carried out with the aim of registering voluntary carbon offsets ("CORCs") for biochar that is applied to agriculture soils with Puro.earth, produced by Sonnenerde in Riedlingsdorf, Austria. The LCA shall establish a proof-of-concept for that production and use of the biochar actually leads to a net decrease in atmospheric carbon dioxide levels.

This LCA is written for acceptance Puro.earth for registration of CORCs in their registry. The report is not necessarily written for public disclosure but can be used for external communication if Sonnenerde wishes to do so. Therefore, the following standards apply:

- **ISO 14040:2006** (International Organization for Standardization [ISO], 2006b)
- **ISO 14044:2006** (International Organization for Standardization [ISO], 2006c)
- **Puro.earth biochar methodology version 2** (Puro.earth, 2022)

Commissioner of the study: Sonnenerde GmbH

Sonnenerde manufactures a range of high-quality substrates and soil improvement products for various scopes. Located in Riedlingsdorf, a village southeast of the Alps in Austria, the company built its first biochar facility all the way back in 2012, making it one of the first European companies to produce biochar from organic waste.

Sonnenerde exclusively uses biogenic waste such as wood scraps, grain husk, sunflower pods, or pulp mud as feedstocks for its biochar production. The biochar is used as aggregate in the production of high-quality substrates or sold as additive for soil amendment, compost, or slurry to both wholesale and private customers.

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LCA practitioner: VästLCA AB

Located in Sweden and founded in 2022, A core idea in VästLCA's working method is that the best decisions can be made with reliable and transparent data as a basis. We consider it necessary to understand the complexities and values that are made in a life cycle assessment and try to encourage the recipient to understand and act on these.

VästLCA believes that most actors in the business world want to do the right thing for themselves and act in the best interests of the planet but are sometimes lost on how to go about achieving this. This is where VästLCA wants to step in with experienced sustainability consultants and help decision-making with data so that in-house experts can make decisions with the best possible basis.

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Pictured on front page: Sonnenerde's biochar facility in Riedlingsdorf, Austria

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Acronyms and abbreviations

CO_2 eq – Carbon dioxide equivalents

DM – Dry matter

EoL – End of Life

GLO – Global

GWP – Global Warming Potential

ISO – International Organization for Standardization

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

RER – The European region

RoW – Rest of the world

1. Introduction

1.1 Sustainable Development

In the report "Our Common Future", also known as the "Brundtland Report". The United Nations define sustainable development as:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Imperatives, S, 1987)

This means that ecological sustainable development must ensure that future generations are not worse of due to the activities we perform today. With climate change, biodiversity loss, land change and natural exceedance of Phosphorous and Nitrogen potentially causing immense problems in the biosphere (Rockström, et al., 2009), there is a need for organizations to understand and act on the way that their operations burden the nature, human health, and resources. A tool for understanding this is LCA (Life Cycle Assessment).

1.2 The role of Life Cycle Assessment

"LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave)." (International Organization for Standardization [ISO], 2006c)

LCA asks the fundamental question "How much environmental burden does this product contribute to?". A key concept in LCA is to relate this to the function of the product, meaning for instance that making a product that will last longer compared to an identical one will show a lower environmental burden, as it can be used more times.

LCA can be used for a myriad of different applications, including but not limited to:

- Internal understanding of environmental impacts
- Understanding and exploring different types of product-system (e.g., Co-ownership or rental models)
- Communicating environmental impacts to other stakeholders
- Understand how your product compares to similar ones the same market
- Comparing different production methods or suppliers

2. Life Cycle Assessment methodology

Life cycle assessment or LCA (also known as life cycle analysis) is a methodology for assessing potential environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).

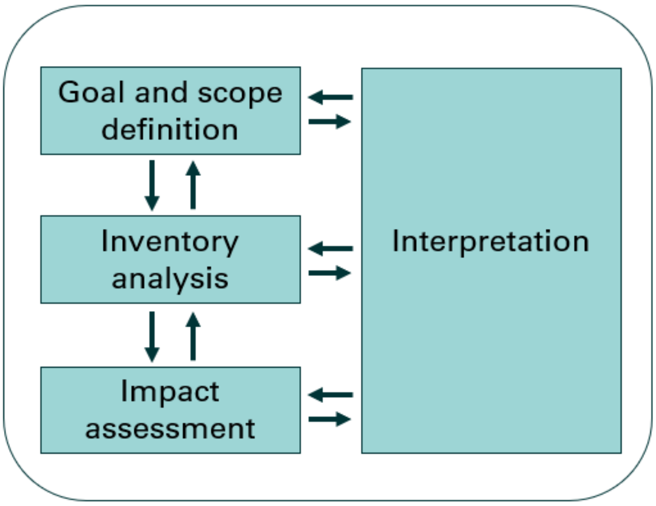

Figure 1: ISO 14040 Framework (International Organization for Standardization [ISO], 2006b)

An LCA study involves a thorough inventory of the energy and materials that are required across the industry value chain of the product, process, or service, and calculates the corresponding emissions to the environment. LCA thus assesses cumulative potential environmental impacts. The aim is to document and improve the overall environmental profile of the product.

Widely recognized procedures for conducting LCAs are included in the 14000 series of environmental management standards of the International Organization for Standardization (ISO) in ISO 14040 and ISO 14044. ISO 14040 provides the 'principles and framework' of the Standard, while ISO 14044 provides an outline of the 'requirements and guidelines'. Generally, ISO 14040 was written for a managerial audience and ISO 14044 for practitioners. As part of the introductory section of ISO 14040, LCA has been defined as the following:

LCA studies the environmental aspects and potential impacts throughout a product's life cycle (i.e., cradle-to-grave) from raw materials acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, ecological consequences and how they relate to social welfare activities. (Fava, et al., 1993)

3. Goal and Scope

3.1 Goal of the study

Sonnenerde GmbH has commissioned the LCA for the purpose of registering CORCs registered with Puro.earth. CORCs are voluntary carbon offset credits that other actors can purchase to cancel out their own emissions. 1 CORC = 1 ton of CO2,eq.

The purpose of the LCA is to prove the carbon removal capacity of the biochar production system.

3.2 Scope of the study

3.2.1 The Studied product system

The studied product is the manufacturing of biochar through pyrolysis from grain husks from grain cleaning of spelt and sunflowers, as well as wood screening residue from the Sonnenerde composting plant, which is then used as aggregate in the production of substrates or sold as additive for soil amendment, compost, or slurry.

The purpose of the biochar is:

1. Sequestration of atmospheric CO_2, which remains stable in the ground when in biochar form.
2. Soil-improving properties of the biochar

The biochar is produced at Sonnenerde's facility in Riedlingsdorf, Austria.

The following stages are included in the study:

A1 – Waste biomass (no activity as the biomass residue is a waste and not a raw material)

A2 - Transport of grain husks to pyrolysis site

A3 –Pyrolysation into biochar

A4 – Transport to fields where the biochar will be applied to agricultural soils.

B1 – Application of the biochar and carbon leakage within 100 years.

When producing the biochar, there is heat produced as a co-product, however this heat is not assessed in this LCA and all associated emissions are allocated to the biochar.

Full details are found in chapter 4 Life cycle inventory.

Physical characteristics of the biochar

The following physical properties are used in the LCA:

Property	Quantity	Reference
Organic Carbon content (C_{org})	0.551 kgC/kg	Reference from elemental analysis, see Appendix A
Hydrogen Content (H)	0.006 kgH/kg	Reference from elemental analysis, see Appendix A
Permanence factor ($F_p^{TH,Ts}$)	0.9564	Calculated from organic carbon content, hydrogen content, and regression coefficients c and m. Values for regression coefficients are retrieved from Puro.earth biochar methodology for a soil temperature of 15 °C (global average)

Table 1: Product content description

3.2.2 Declared unit

The declared unit is 1 ton of dry biochar applied to soils. The results will present the potential carbon sequestration from the declared unit.

3.2.3 System boundary

The studied system is a cradle-to-grave within a 100-year time boundary. Infrastructure is included.

A brief description of the modules is presented below:

Module	Included Activities
A1	No activities as the waste is precured burden-free.
A2	Transport of grain husks to the pyrolysation site
A3	Consumption of wood pellets for startup and electricity for operation of pyrolyser. Flue gas emissions, packaging, diesel consumption for initiating drying of grain husks, and infrastructure for pyrolysis process.
A4	Transporting the biochar to end consumer where it will be applied
B1	Fuel for spreading the biochar and the carbon leakage that occur within 100 years from application.

Table 2: Description of activities in the modules

A general description of the system boundaries can be seen below (Adapted from the Puro.earth methodology document).

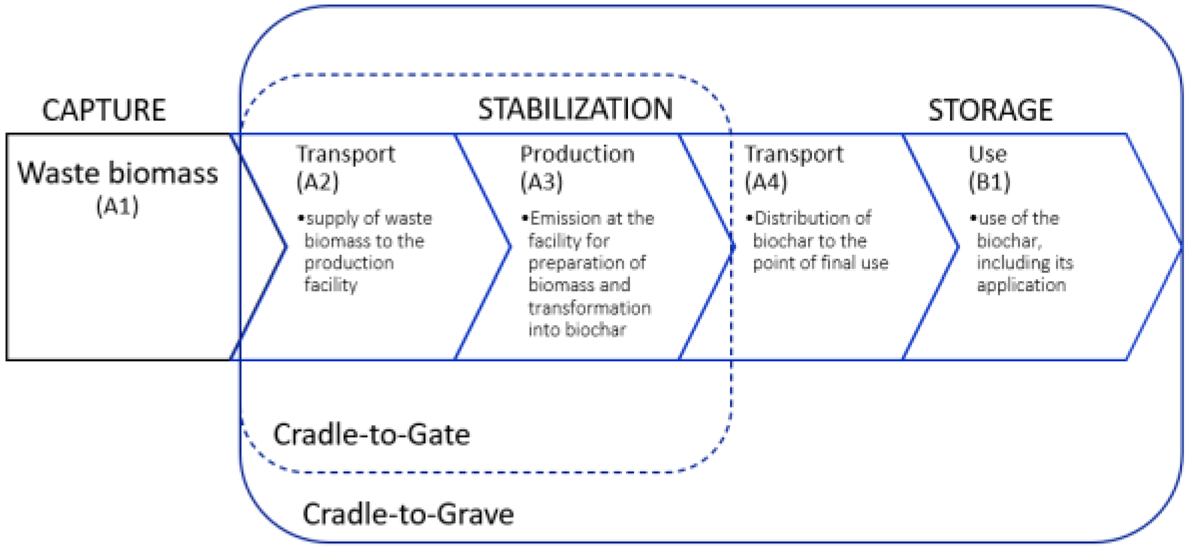

Figure 2: System boundary, from (Puro.earth, 2022)

3.2.4 Assumptions

This chapter deals with general assumptions that are used throughout the LCA study. For assumptions relating to specific unit processes, see the LCI tables in chapter 4.4.

- Assume carbon content of grain husk is based only on sunflower due to availability of data
- The feedstock has to be stored for approximately 1,5 months due to irregular deliveries by Sonnenerde's suppliers, however, as the feedstock is not stored for a longer period before drying to below 20% water content, no methane emissions due to self-heating were considered

- The production volume modelled was based on a target annual volume of 800 tonnes. The elemental analysis of the biochar was, however, based on a report by Eurofins (see appendix) for a batch produced during September 2023

3.2.5 Cut-off criteria

The cut-off criteria is set to 1% of the renewable and non-renewable primary energy use and max 1% of the total mass input of a specific unit process.

In this study, exiting flue gases that are not CO_2 or CH_4 are assumed to be below cut-off.

3.2.6 The LCAs allocation procedure

Allocation in this LCA is performed according to ISO 14044, which is done in the following order of priority:

Step 1 – Avoid allocation by dividing the unit processes into sub-processes or expanding the product system to include additional functions.

Step 2 – Partitioning the inputs and outputs of the system between its different products or functions in a way that reflects the underlying physical relationships between them. Examples of this is mass or energy.

Step 3 – Partitioning the inputs and outputs of the system between its different products or functions in a way that reflects other relationships between them. Examples of this is economic value.

3.2.6.1 Energy allocation

According to Puro.earth Biochar methodology v.2, any pyrolysis co-products representing high-value products needs to have an energy allocation applied between the biochar and the co-product. In the case of Sonnenerde's PyroDry system, the majority of waste heat is used to dry industrial sewage sludge, which is then pelletized and delivered to a waste disposal company. The drying and pelletizing of sewage sludge is provided as a service to the company, whereas the remaining waste heat is used for drying the biomass for biochar production as well as heating company buildings.

The total thermal output of the PyroDry system is 500 kW, of which around 350 kW is used for system operation. The remaining 150 kW of the thermal output remains in the Biochar. Based on this data, 30% of the impacts from the following processes was allocated to the production of the Biochar:

- **A2 Transportation** – transportation of biomass to Sonnenerde facility
- **A3 Production** – water quenching and use wood pellets for startup fuel
- **A3 Production** – Infrastructure requirements for pyrolysis
- **A3 Production –** Diesel consumption for handling of biomass
- **A3 Production –** Electricity consumption

3.2.7 Data quality

Foreground and background data quality will be evaluated in the interpretation chapter.

Foreground system data quality

The foreground system represent the direct inputs into the life cycle, such as:

- Amount of feedstock needed to produce 1 ton biochar

- Amount of electricity required in production
- Biochar transport distance

Background system data quality

The background system consists of all non-specified inputs that happen upstream or downstream which are indicated by the flows in a dataset (such as when the foreground system specifies 1 kg of steel, the extraction of raw iron and its processing is included in the background system).

3.2.8 LCIA methods

The only relevant impact category for this LCA is Climate Change, which is measured according to the details below.

Impact Category	Indicator	Unit	Original reference
Climate Change	Global Warming Potential including CO2 uptake	kg CO_2 eq. (Carbon dioxide)	Baseline model of 100 years of the IPCC based on IPCC 2021

Table 3: Global warming method reference

3.2.9 Limitations

This study only focuses on the environmental impact indicator Climate Change.

This study does not assess the data uncertainty as the goal is to produce a fixed number for CORCs issuance (the mean), and the spread above and below the mean is irrelevant.

3.2.10 Critical review

The report has not gone through a formal critical review according to ISO 14071 but has been internally reviewed by Puro.earth.

4. Life Cycle Inventory

4.1 Method for data collection

The following data was collected based on existing operations from the pyrolysis site.

- Transportation distance and fuels to and from the site
- Biochar elemental analysis
- Startup fuel
- Electricity consumption
- Packaging material

4.2 Description of the product system

The input biomass is based on two different feedstock from three sources:

- Grain husk after grain cleaning of spelt and sunflowers from supplier 1
- Grain husk after grain cleaning of spelt and sunflowers from supplier 2
- Wood screening residue from the Sonnenerde composting plant

The feedstock is dried with low temperature exhaust energy from the pyrolysis process. The feedstock is then transported by a worm screw in a closed pipe which in the center of the burning chamber.

4.3 Used software and databases

The LCA was modelled in SimaPro 9.5 using ecoinvent 3.9.1 and AGRIBALYSE 3.0.1 as the databases. The specific datasets used for the unit processes can be seen in the tables presented in this chapter.

4.4 Full Life Cycle Inventory

This chapter presents the complete amounts and the unit processes that were used in the LCA model. All amounts are per 1 tonne dry biochar. The presented values in this chapter are after allocation has been performed.

4.4.1 Calculation procedures for 1 ton produced biochar

Sonnenerde reported a 38.3% yield from their pyrolysis based on the inputs of feedstock and output of biochar by mass. The full carbon flows without any subtractions can be seen on the following page.

Factors and assumptions		Legend
Biomass moisture content	5.0%	DM = Dry matter
Biomass carbon content	47.0%	w% = Weight percentage
Biomass carbon content (DM)	49.5%	Activity inside system boundary
Biochar carbon content	55.1%	Activity outside system boundary
Biochar water content	31.4%	Calculated value
Biochar Yield	38.3%	Given value
c	1.04	Assumption
m	-0.64	Literature value
Organic Hydrogen content	0.6%	Input of material or energy
H/C Ratio	0.13	Direct emissions
Permanence factor	95.64%	

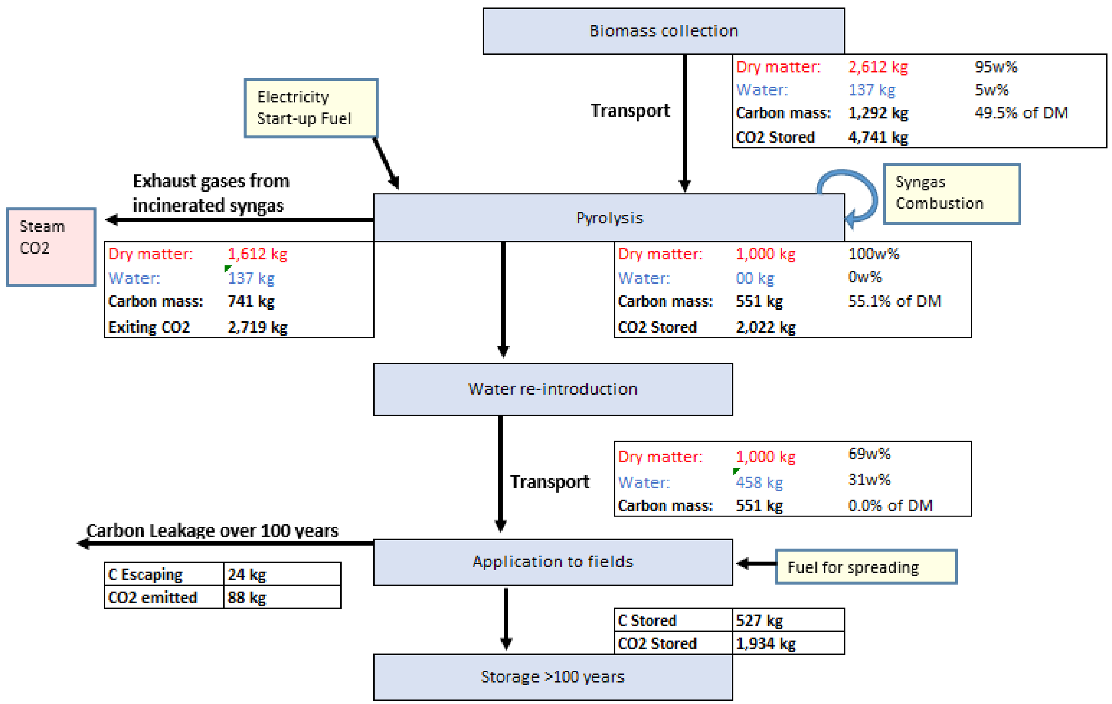

Figure 3: Carbon flowchart

4.4.2 A1 – Waste biomass

No activities are reported in A1 as the sourced biomass is waste.

The Carbon weight as biogenic carbon uptake was calculated by taking the weighted average of each feedstock from the suppliers, described in the table below:

Biomass	Carbon content	Dry weight, in tonnes (per functional unit)	Source of carbon content	Comment
Grain husks from supplier 1	50%	0.12	Phyllis2 (TNO, 2023)	Carbon content is from sunflower husk (dry)
Grain husks from supplier 2	50%	0.12	Phyllis2 (TNO, 2023)	Carbon content is from sunflower husk (dry)
Wood screening residue from Sonnenerde facility	49.4%	2.38	Phyllis2 (TNO, 2023)	Carbon content is from wood, demolition wood, chipped (dry)
Weighted average carbon content	**49.5%**			

Table 4: Carbon content for each biomass and weighted average calculated

Reported input of 1 292 kg Carbon as biogenic carbon uptake (49.5% of DM).

4.4.3 A2 – Transport to production facility

Transport	Distance (km)	Amount wet weight in tonnes (per functional unit	Used dataset in LCA model	Comments
Road, from supplier 1 to Biochar production facility	200	0.126	Transport, freight, lorry 7.5-16 metric ton, EURO6 {RER}| transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, U	30% of transport impacts are allocated to the biochar.
Road, from supplier 2 to Biochar production facility	13	0. 126	Transport, freight, lorry 7.5-16 metric ton, EURO6 {RER}| transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, U	30% of transport impacts are allocated to the biochar.

Table 5: Material transport distances

4.4.4 A3 – Manufacturing

This chapter describes all processes that are under Sonnenerde's control and take place in the manufacturing facility.

Activity	Amount	Unit	Used dataset in ecoinvent or other	Comment
Outputs				
Biochar	1 000	Kg		
Carbon dioxide	2 719	kg	Carbon dioxide, biogenic	From remaining carbon in biomass mixture not turned into biochar
Inputs				
Sunflower husk	237	Kg	Burden-free	Dry weight
Wood screen residue	2 380	Kg	Burden-free	Dry weight
Infrastructure	0.438E-05	Pieces	Industrial furnace, natural gas {RER}| industrial furnace	Infrastructure needed for PyroDry, see calculations below

			production, natural gas | Cut-off, U	
Wood pellets for startup	0.528	MJ	Heat, central or small-scale, other than natural gas {CH}| heat production, wood pellet, at furnace 25 kW | Cut-off, U	Wood pellets used as startup fuel. Modified dataset to include Austrian electricity dataset instead of original from Switzerland. (Electricity, low voltage {AT}| market for electricity, low voltage | Cut-off, U)
Electricity from installed solar PV	90	kWh	Electricity, low voltage {AT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U	Electricity consumption for operating PyroDry from installed solar panels. Assumed half of the electricity consumption is from installed panels and the remaining half is from grid. The energy used for sewage sludge drying and pelletizing is also allocated to the Biochar production, therefore the model presents a conservative approach to the energy requirement of the pyrolysis process.
Electricity from Hydropower (grid)	20.49	kWh	Electricity, high voltage {AT}| market for electricity, high voltage | Cut-off, U (adjusted, dataset renamed to Electricity AT market Hydropower)	22.77% from Hydropower (of the 300 kWh from grid), based on guarantee of origin, see appendix. This dataset was adjusted by removing all sources in inputs from technosphere: electricity/heat except for hydropower datasets. The output of the hydropower datasets was summarized to an output. This output was used to scale the emissions to air accordingly as well as adjust the output of the dataset.
Electricity from Wind power (grid)	66.65	kWh	Electricity, high voltage {AT}| market for electricity, high voltage | Cut-off, U (adjusted, dataset renamed to Electricity AT market Wind power)	74.06% from Wind power (of the 300 kWh from grid), based on guarantee of origin, see appendix. This dataset was adjusted by removing all sources in inputs from technosphere: electricity/heat except for wind power datasets. The output of the wind power datasets was summarized to an output. This output was used to scale the emissions to air accordingly as well as adjust the output of the dataset.
Electricity from solar PV (grid)	2.85	kWh	Electricity, low voltage {AT}| market for electricity, low voltage |Cut-off, U	3.17% from Solar PV (of the 300 kWh from grid), based on guarantee of origin, see appendix.
Water	458	Kg	Tap water {RER}| market group for tap water | Cut-off, U	Water used for quenching. The value is based on the moisture content of the biochar (31.4%)
Diesel	27.24	MJ	Diesel, burned in building machine {GLO}| diesel, burned in building machine | Cut-off, U	Diesel used for handling grain husks on site (mixing, and feeding to reactor), also includes biochar handling with same wheel-loader. No diesel consumption required for processing of wood screening residue.

Table 6: Activities for pyrolyzing the feedstock required for 1 ton biochar

The biochar facility targets a volume of 800 tonnes of biochar per year of dry mass. This volume target was used as the basis of the modelling, with the estimated biomass requirement of 1 900 + 190 tonnes of biomass.

The infrastructure needed was calculated by using the dataset *Biomethane, high pressure {CH}| biomethane production, high pressure from synthetic gas, wood, fixed bed technology | Cut-off, U,* which reports 2.15 E-08 p infrastructure for an input of 3.8 kg feedstock, as a base for calculating the value for industrial furnace from the total amount of biomass required by Sonnenerde. This was done through the following method:

1) $3.8\ kg\ wood\ chips = 2.15E-08\ pieces\ industrial\ furnace$

2) $\frac{2.15E-08\ pieces\ industrial\ furnace}{3.8\ kg\ wood\ chips} = 5.60E-09\ pieces\ of\ industrial\ furnace\ per\ kg\ wood\ chips$

3) $2\ 617\ kg\ biomass\ for\ Pyreg\ 500 * 5.60E-09\ pieces\ of\ industrial\ furnace\ per\ kg\ wood\ chips = 1.46E-05$

The ratio of kg wood chips to pieces industrial furnace was taken from the Biomethane dataset mentioned above. There is a high uncertainty in this value and dataset chosen, however it is deemed to be a relatively close approximation of the infrastructure based on the datasets available. The amount of wood chips was also assumed to represent an equivalent amount to the biomass of Sonnenerde for simplifying the infrastructure calculation. The GWP100 fossil impact from the infrastructure dataset only represents 0.03% of the total result, and is therefore deemed to be negligible, making the high uncertainty in this dataset irrelevant.

The startup fuel was reported to be 100 kg of wood pellets where the ignition energy comes from electric hot air blowers. In the dataset used for wood pellets, described in the table above, the amount of wood pellets used as input is approximately 0.07 kg. In order to scale this to the functional unit, the following equation was used:

4) $\frac{100\ kg\ wood\ pellets\ for\ reactor\ startup\ fuel}{800\ tonnes\ Biochar\ produced} * \frac{1}{0.07} = 1.76$

The ratio of 1.76 was used to scale the output of the dataset for wood pellets required for startup fuel (table shows value in MJ as it is the output of the dataset).

4.4.4.1 Packaging

The table below presents the packaging used for 1 000 kg biochar produced.

Input	Value	Unit	Used dataset in LCA model
Polypropylene granulate	3.15	Kg	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, U
EUR-flat pallet	0.04	Pieces	EUR-flat pallet {RER}| EUR-flat pallet production | Cut-off, U
Plastic film extrusion	3.15	Kg	Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, U

Table 7: Packaging input values for 1 000 kg of Biochar produced

Plastic film extrusion dataset defines an efficiency of 97.6%, therefore an adjustment was made in order to account for the loss in the process (both the extrusion and the amount of polypropylene granulate).

One EUR-flat pallet is assumed to be used for 1 tonne biochar. Since Sonnenerde uses exchange pallets, an assumption is made that the pallet is used 25 times, therefore corresponding to a value of 0.04 pallets per ton biochar.

The packaging required for the PyroDry biochar was based on the amount needed for Sonnenerde's Pyreg 500 biochar production, where the amount of polypropylene granulate per kg (326 kg of packaging for 72.8 tonnes of biochar (dry weight), resulting in 4.47 kg packaging per tonnes of biochar. This means that producing 800 tonnes of Biochar would require 3 576 kg of packaging material.

By dividing the value of 3 576 kg by the total weight of the PyroDry production in wet weight of 1 166 tonnes (moisture content of the Biochar is 31.4% based on Eurofins report, see appendix), the required amount of packaging per functional unit is therefore approximately 3.07 kg.

The plastic extrusion dataset does however state 1 kg of the process is equivalent to 0.976 kg extruded plastic film. In order to take this into account, the packaging required was adjusted by dividing 3.07 kg with 0.976, resulting in 3.15 kg polypropylene granulate needed per tonnes biochar produced.

4.4.5 A4 – Transport to customer

Transport	Distance	Used dataset in LCA model	Comment
Road	72.9 tkm	Transport, freight, lorry 7.5-16 metric ton, EURO6 {RER}| transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, U	Distance to end customer provided by Sonnenerde, assumed 100 km.

Table 8: Transport to customer from production facility

The biochar is either transported to end customer or incorporated directly into Sonnenerde's soil products at site. Half of the Biochar is transported an assumed distance of 100 km to end customer, whereas the other half that is incorporated into Sonnenerde's soil products at their facility are not transported. As a result, 50% of the Biochar (corresponding to 500 kg based on the functional unit) is transported 100 km, whereas the remaining 500 kg does not have any transport in module A4 allocated.

4.4.6 B1 – Soil application

Activity	Amount	Unit	Used dataset in ecoinvent or other	Comment
Biochar spreading	721.5	seconds	Harrowing, with rotary harrow (standard equipment)/FR U From Agribalyse 3	4m wide harrower 2 m/s speed 1 ha = 100x100m = 10 000m2 4 m width = 25 laps to harrow 100 m 2 m/s = 50 seconds for 1 lap (60 seconds with turning) 60*25 = 1500 seconds 48.1%*1500 = 721.5 seconds Assumption that 1 ton biochar is used on 1 ha
Carbon leakage over 100 Years	88	Kg CO_2	Direct emission of CO_2	Based on calculation guidance for biochar permanence factor in (Puro.earth, 2022) (15 °C soil) and the supplied H/C ratio in appendix A
Packaging waste treatment	3.15 + 1.04	Kg	Waste plastic, mixture {AT}| market for waste plastic, mixture | Cut-off, U + Waste wood, untreated {AT}| market for waste wood, untreated | Cut-off, U	Plastic waste (3.15 kg) + wood waste from pallet (1.04 kg). The wood waste was calculated assuming weight of one EU pallet being 26 kg, multiplied by the use rate of the pallet (0.04, see description in 4.4.4.1)

Table 9: Activities in B1 and carbon leakage over 100 years

For the application of the Biochar, 48.1% of the total biochar produced is reported to be applied into soil by rotary harrow based on Sonnenerde's Pyreg 500 biochar production. Assuming that the customer base remains similar, the same share is applied to Sonnenerde's PyroDry biochar production. As a result, 48.1% of the Biochar (corresponding to 481 kg based on the functional unit) uses a rotary harrow to incorporate Biochar into soil. The remaining 51.9% of the Biochar is incorporated into the soil by hand, for example sprinkled on compost heap.

5. Life Cycle Impact Assessment

This chapter presents all results from the LCA. All results are presented per ton biochar produced.

The results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

5.1 Summarized results for CO_2 uptake and emissions

Environmental impact category	Included origins	Unit	Total	A1 - Biomass per ton biochar	A2 - Transport	A3 - Production	A4 - Biochar transport to customer	B1 - Biochar Use
Climate Change	Fossil Biogenic LULUC	Kg CO2 eq. (Carbon dioxide equivalents)	-1875	-4741	2	2740	17	108

Table 10: Total GWP results

Below is a Sankey diagram showing the sources of uptake and emissions[1].

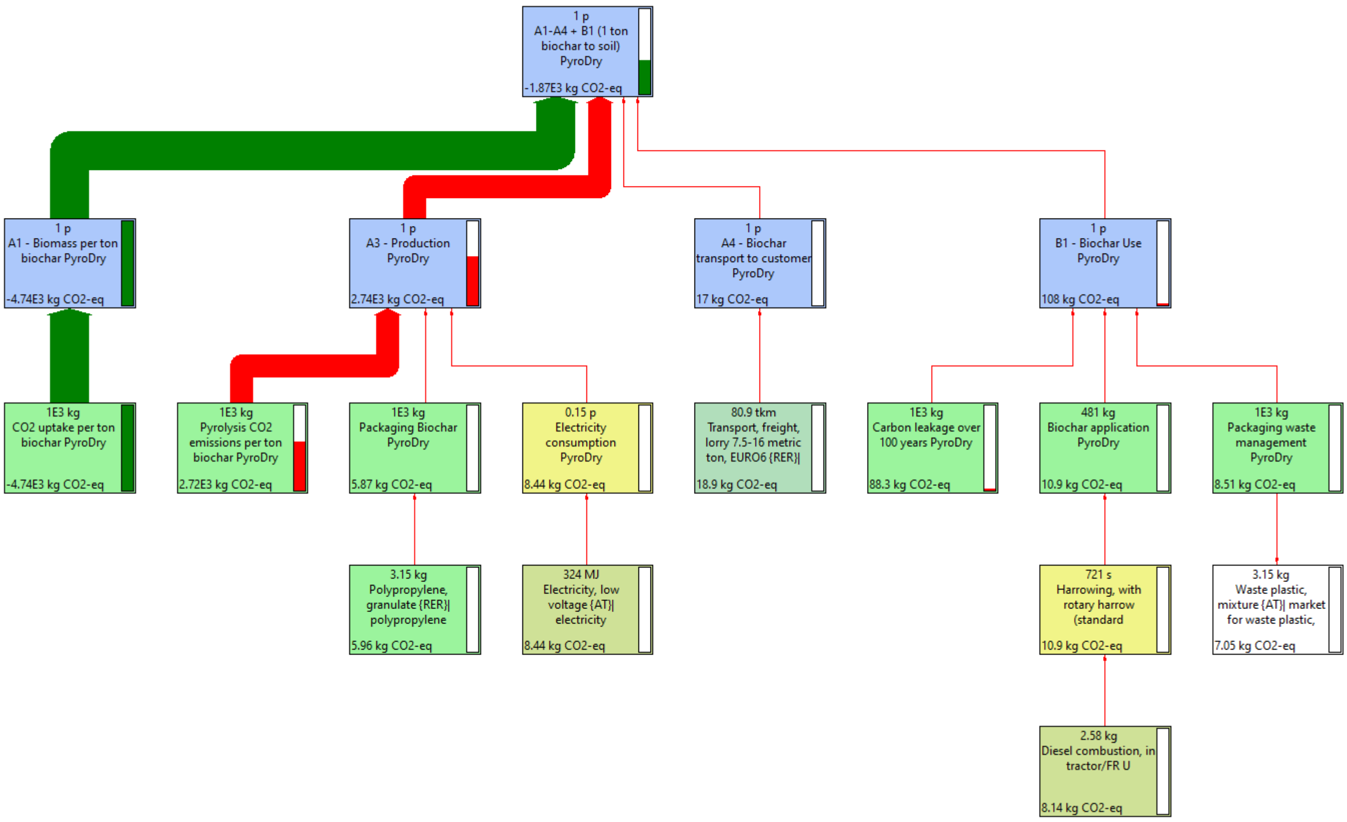

Figure 4: Sankey diagram for CO2 uptake and emissions for 1 ton biochar

[1] Some figures may vary slightly from table 10 due to rounding

5.2 Detailed results for all emissions

The ecoinvent End User License Agreement (EULA) allows for sharing non-aggregated LCIA results for up to 5 datasets[2]. The results are therefore presented per module as presented in the PURO.earth methodology as to not publicize the specific datasets.

Specific data can be viewed by ecoinvent license holders in a separate appendix.

Contribution phase (Activity)	**Result per ton of biochar produced and applied to field (CO_2-eq)**					
Life cycle stage	Captured biogenic CO2	Fossil CO_2	Emitted Biogenic CO_2	CH_4 emissions	Other Greenhouse gases	Total
Estored	-4741.3	0.0	88.2	0.0	0.0	-4653.1
Ebiomass	0.0	1.7	0.0	0.2	0.0	1.9
Eproduction	0.0	16.1	2720.2	2.6	0.8	2739.7
Euse	0.0	32.6	1.6	1.8	0.4	36.5
SUM	**-4741.3**	**50.4**	**2810.0**	**4.6**	**1.2**	**-1875.0**
CORCs (Sum of all above)	**1875,0 kg = 1,88 CORCs**					

Table 11: Detailed GWP results

Below is a Sankey diagram showing the sources of all fossil emissions.

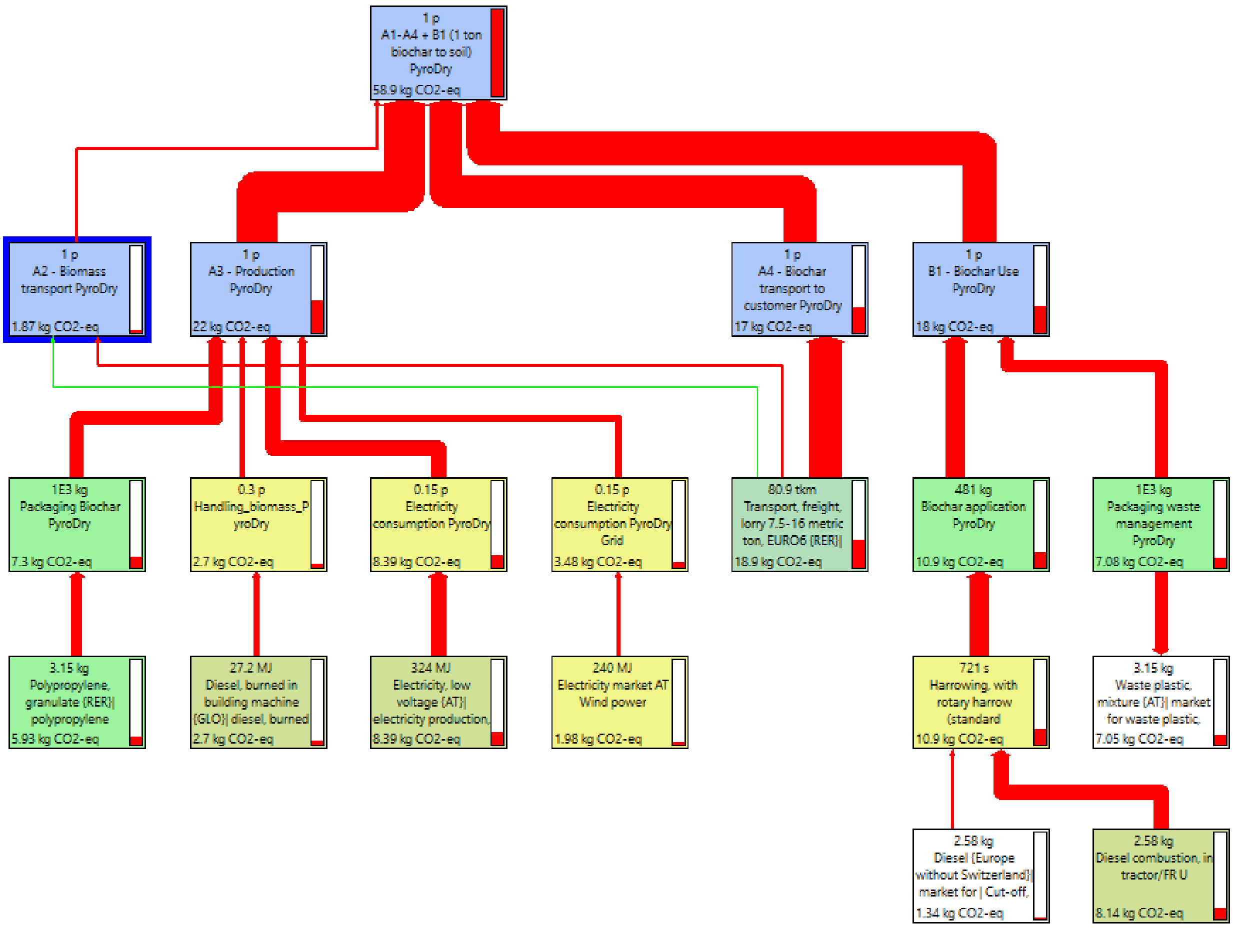

Figure 5: Sankey diagram for fossil CO2 emissions to produce 1 ton biochar

[2] https://ecoinvent.org/wp-content/uploads/2022/09/ecoinvent-EULA_Use-Cases_010922.pdf

6. Interpretation

The combustion of the syngases has the highest contribution to GWP, this is however not unexpected as it is a part of the typical biochar production process. In regard to GWP from other sources, the largest contribution comes from transportation of Biochar to end customer and electricity consumption for the production of biochar.

6.1 Scenario analysis

The baseline modelling scenario is based on the target production volume for the PyroDry system of 800 tonnes Biochar annually, as there is no data available yet that represents a full year of production (the PyroDry system had it's first trial operation in July 2023).

There is, however, data available for a full month of production during September 2023 (total of 37.15 tonnes Biochar produced). In order to evaluate the impact on the end results by using data for both time representations, a scenario analysis was performed. The input data that was altered for the September production values, compared with the baseline scenario, is presented in the table below as per functional unit:

Activity/Parameter	Dataset	Baseline (full year production target)	Scenario (September 2023)	Comment
Grain husk processed	N/A (input parameter)	0.24 tonnes	0.22 tonnes	Reported total biomass processed during September was 90 tonnes. The distribution between grain husks and wood screen residue was the same as the baseline modelling (approximately 9.1% grain husks and 90.9% wood screen residue)
Wood screen residue processed	N/A (input parameter)	2.38 tonnes	2.2 tonnes	Reported total biomass processed during September was 90 tonnes. The distribution between grain husks and wood screen residue was the same as the baseline modelling (approximately 9.1% grain husks and 90.9% wood screen residue)
Pyrolysis CO_2 emissions	Carbon dioxide, biogenic	2.72 tonnes	2.38 tonnes	Assumed same Biochar characteristics, only difference is amount of biomass
Infrastructure requirement	Industrial furnace, natural gas {RER}| industrial furnace production, natural gas | Cut-off, U	0.438E-05 pieces	0.408E-05 pieces	Difference in value due to different amount of biomass processed
CO_2 uptake	Carbon dioxide, biogenic	-4.74 tonnes	-3.59 tonnes	Difference in value due to different amount of biomass processed
Diesel for handling biomass	Diesel, burned in building machine {GLO}| diesel, burned in building machine | Cut-off, U	27.24 MJ	25.26 MJ	Difference in value due to different amount of biomass processed
Electricity from installed solar PV	Electricity, low voltage {AT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U	90.0 kWh	90.9 kWh	The electricity consumption for one month is based on the electricity required for the

Electricity from Hydropower (grid)	Electricity, high voltage {AT}| market for electricity, high voltage | Cut-off, U (adjusted, dataset renamed to Electricity AT market Hydropower)	20.49 kWh	20.70 kWh	pyrolysis unit, counter exhaust air purification, and building. The modelled electricity consumption is split evenly between solar PV installation on site and electricity from grid The energy used for sewage sludge drying and pelletizing is also allocated to the Biochar production, therefore the model presents a conservative approach to the energy requirement of the pyrolysis process.
Electricity from Wind power (grid)	Electricity, high voltage {AT}| market for electricity, high voltage | Cut-off, U (adjusted, dataset renamed to Electricity AT market Wind power)	66.65 kWh	67.32 kWh	
Electricity from solar PV (grid)	Electricity, low voltage {AT}| market for electricity, low voltage |Cut-off, U	2.85 kWh	2.88 kWh	

Table 12: Comparisons of parameter and activity values between the baseline scenario and the September production value scenario

Based on these altered input parameters, the GWP100 including CO_2 uptake is approximately 1.87E+03 kg CO_2-eq, compared to the baseline scenario resulting in 1.88E+03 kg CO_2-eq. This indicates that the difference in uptake is less than 1%, which is a negligible difference and therefore the target production volume seems to be a reasonable estimate for a full year of production.

6.2 Sensitivity analysis

Two sensitivity analysis was performed to determine the impact of changing some key parameters in the modelling. The first analysis is what the impact of different soil temperatures, and consequently the regression coefficients, have on the GWP100 including CO_2 uptake impact. The second analysis concerns the energy allocation to the biochar production process in the PyroDry system.

6.2.1 Soil temperature

The regression coefficients for estimating biochar stability for a time horizon of 100 years vary depending on the soil temperature (as presented in the table below), where the global mean soil temperature of 14.9°C is used for the modelling according to the Puro.earth methodology (Puro.earth, 2022).

Soil temperature	c	m
5°C	1.13	-0.46
10°C	1.10	-0.59
15°C	1.04	-0.64
20°C	1.01	-0.65
25°C	0.98	-0.66

Table 13: Regression coefficients based on soil temperature (Puro.earth, 2022)

The different soil temperatures assumed in the LCA model have a noticeable impact on the potential CO_2 uptake potential of the biochar, and therefore a sensitivity analysis was performed on this parameter. The figure below shows the total GWP100 potential impact including CO_2 uptake based on the different soil temperatures[3].

[3] The baseline figure varies slightly due to rounding differences

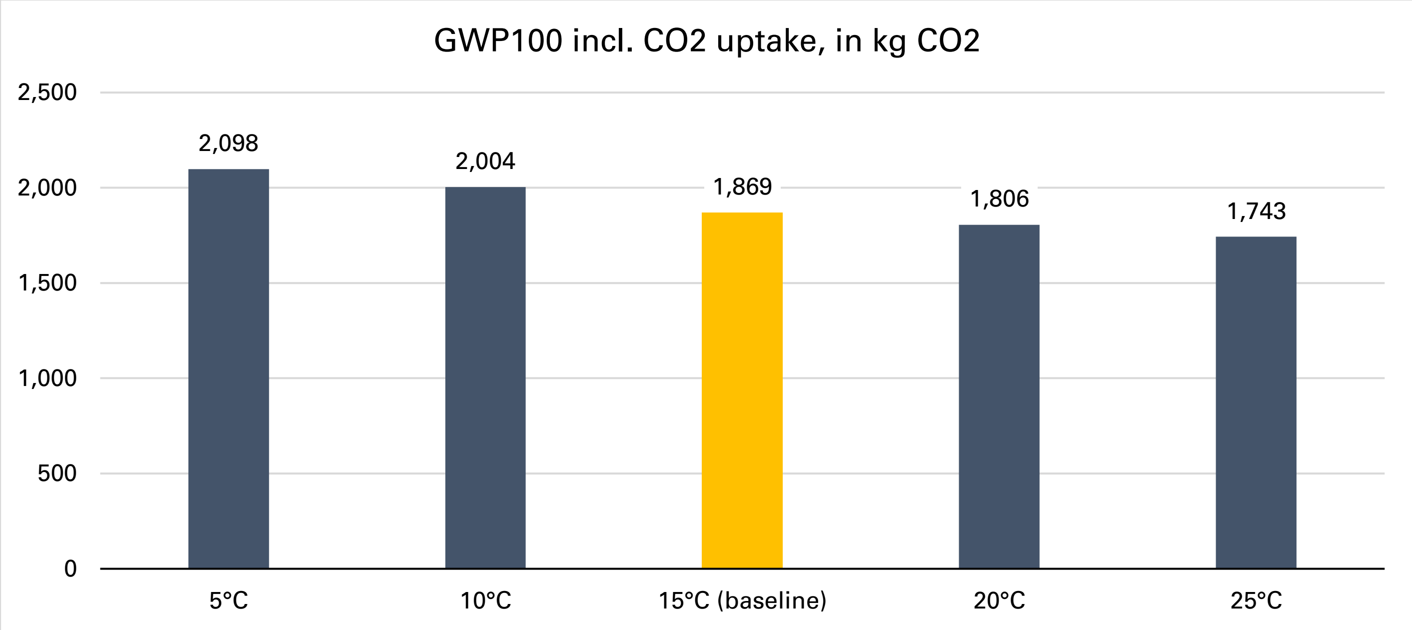

Figure 6: GWP100 including CO_2 uptake for different soil temperatures

The results show that the GWP100 potential impact including CO_2 uptake varies with approximately +12% / -7%.

6.2.2 Energy allocation

The baseline scenario for the energy allocation is 30% in the modelling (based on the thermal output of the Pyrolysis process, where 30% remains in the Biochar). In order to evaluate the impact of varying degrees of thermal output remaining in the Biochar, three other allocation factors were considered, where the difference in impact on GWP100 including CO_2 uptake is shown in the figure below.

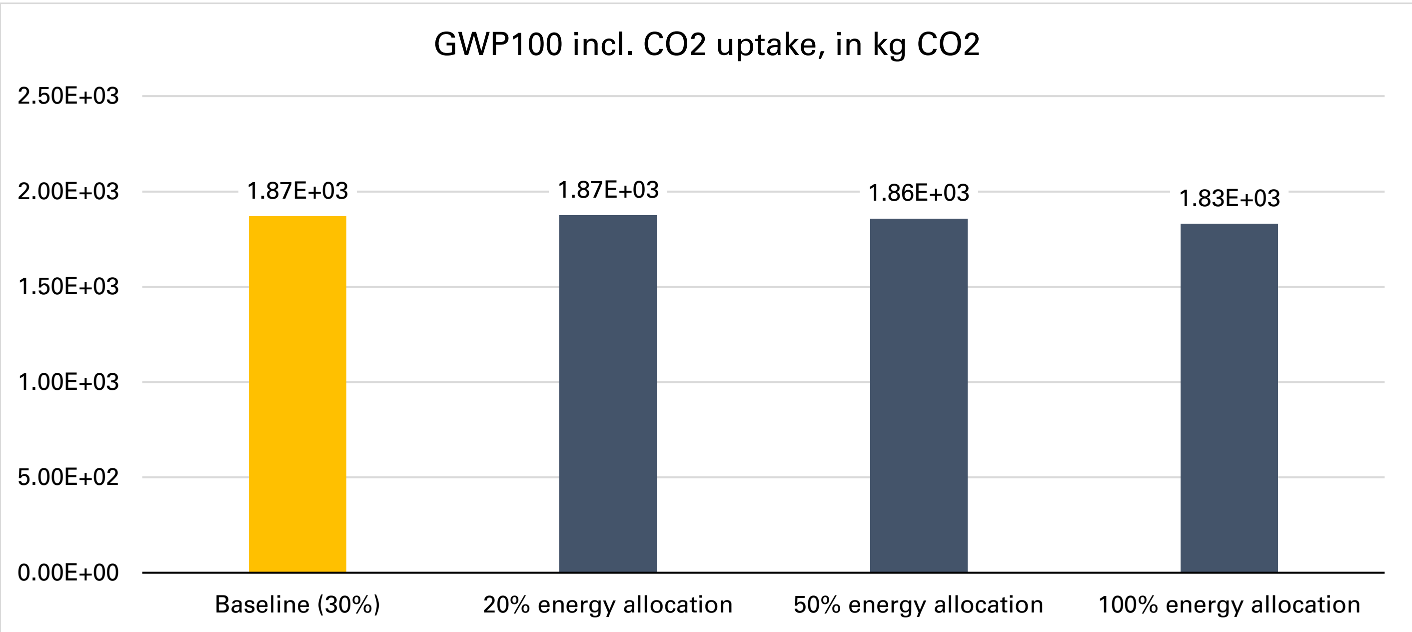

Figure 7: GWP100 including CO_2 uptake for different energy allocations of the Biochar production in the PyroDry system

The results show that even allocating all of the impact from the pyrolysis process to the Biochar, the result only differentiates by approximately 2%. Therefore, this parameter does not have a significant impact on the GWP100 including CO_2 uptake results.

6.3 Conclusion for CORCs issuance

1 ton of biochar (DM) that is applied to fields in Austria produced by Sonnenerde in Riedlingsdorf through pyrolysis of grain husks from grain cleaning of sunflowers, and wood screening residue from the Sonnenerde composting plant, has a carbon sequestration potential of **1 875 kg CO2,eq** over 100 years.

This equals **1,88 CORCs**, meaning that **1 CORC** requires **532 kg biochar (DM)**

1 ton of biochar (DM) needs 249 kg of grain husks (wet weight, 5% moisture content) and 2 505 kg of wood screening residue (wet weight, 5% moisture)

6.4 Data quality assessment

This chapter assesses the data quality of the LCA. The assessment is divided between the background system (datasets) and the foreground system (quantities) The data quality assessment is based on the criteria of the UN Environment Global Guidance on LCA database development.

6.5 Background system data quality assessment

Data Quality	Data Quality Assessment
Time related coverage	**Very Good** as all datasets are currently valid and all figures are from 2023.
Geographical coverage	**Foreground:** Very good, all figures comes from the actual site. **Background:** Fair, the datasets have been chosen for Austria when available, and complemented with European or Global when needed.
Technology coverage	**Very good**, all figures comes from the actual site. Some values are projected values.
Other Data Quality indicators	
Precision	As all relevant flows are reported directly (from site or eurofins report), the precision is considered good.
Completeness	All known relevant flows are accounted for.
Representativeness	Very good, only the actual site has been assessed.
Consistency	Very good, all stages utilize a consistent methodology.
Reproducibility	The LCA is reproducible with all data reported in this report. No other data was used then what is reported in this document.
Data sources	Data collection method is described in the LCI chapter, and all datasets are referenced.
Data uncertainty	The data uncertainty has not been assessed in this report as the goal is to produce a fixed number for CORCs issuance (the mean), and the spread above and below the mean is irrelevant. However, as all figures comes from direct measurements, the uncertainty should be low.

Table 14: Data Quality Assessment

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Appendix A – Elemental analysis of Biochar

eurofins | Umwelt

Eurofins Umwelt Ost GmbH - Lindenstraße 11 - Gewerbegebiet Freiberg Ost - D-09627 Bobritzsch-Hilbersdorf

SONNENERDE GmbH
Oberwarterstraße 100
7422 Riedlingsdorf
ÖSTERREICH

Titel:	**Prüfbericht zu Auftrag 12341776**
Prüfberichtsnummer:	**AR-23-FR-046984-01**
Auftragsbezeichnung:	**Pflanzenkohle von Pyrolyseanlage PyroDry**
Anzahl Proben:	**1**
Probenart:	**Pflanzenkohle**
Probenehmer:	**keine Angabe, Probe(n) wurde(n) an das Labor ausgehändigt**
Probeneingangsdatum:	**21.09.2023**
Prüfzeitraum:	**21.09.2023 - 10.10.2023**

Die Prüfergebnisse beziehen sich ausschließlich auf die untersuchten Prüfgegenstände. Sofern die Probenahme nicht durch unser Labor oder in unserem Auftrag erfolgte, wird hierfür keine Gewähr übernommen. Dieser Prüfbericht enthält eine qualifizierte elektronische Signatur und darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen in jedem Einzelfall der Genehmigung der EUROFINS UMWELT.

Es gelten die Allgemeinen Verkaufsbedingungen (AVB), sofern nicht andere Regelungen vereinbart sind. Die aktuellen AVB können Sie unter http://www.eurofins.de/umwelt/avb.aspx einsehen.

Das beauftragte Prüflaboratorium ist durch die DAkkS nach DIN EN ISO/IEC 17025:2018 DAkkS akkreditiert. Die Akkreditierung gilt nur für den in der Urkundenanlage (D-PL-14081-01-00) aufgeführten Umfang.

Anhänge:
XML_Export_AR-23-FR-046984-01.xml

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Digital signiert, 10.10.2023
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Prüfleitung

DAkkS
Deutsche Akkreditierungsstelle
D-PL-14081-01-00

Parameter	Lab.	Akkr.	Methode	EBC-Futter-Plus	EBC-Futter	EBC-AgroBio	EBC-Agro	EBC-Urban	EBC-Gebrauchsmaterial	EBC-Rohstoff	BG	Einheit	anl	wf
				Vergleichswerte							Probenbezeichnung		Pyrolyseanlage PyroDry Pflanzenkohle	
											Probennummer		123149317	
Eigenschaften der Pflanzenkohle														
Gesamtwassergehalt	FR	F5	DIN 51718: 2002-06								0,1	Ma.-%	31,4	-
Aschegehalt (550°C)	FR	F5	DIN 51719: 1997-07								0,1	Ma.-%	29,2	42,6
Aschegehalt (815°C)	FR	F5	DIN 51719: 1997-07								0,1	Ma.-%	26,9	39,2
Kohlenstoff gesamt	FR	F5	DIN 51732: 2014-07								0,2	Ma.-%	37,8	55,1
Wasserstoff	FR	F5	DIN 51732: 2014-07								0,1	Ma.-%	0,4	0,6
Stickstoff, gesamt	FR	F5	DIN 51732: 2014-07								0,05	Ma.-%	0,43	0,63
Schwefel (S)	FR	F5	DIN 51724-3: 2012-07								0,03	Ma.-%	0,16	0,24
Sauerstoff	FR	F5	DIN 51733: 2016-04									Ma.-%	2,9	4,2
pH in CaCl2	FR		DIN ISO 10390: 2005-12										12,4	-
Bestimmung aus dem Mikrowellendruckaufschluss nach DIN 22022-1: 2014-07														
Arsen (As)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01			13	13	13	13		0,8	mg/kg	-	3,1
Blei (Pb)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01			45	120	120	120		2	mg/kg	-	8
Cadmium (Cd)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01			0,7	1,5	1,5	1,5		0,2	mg/kg	-	< 0,2
Kupfer (Cu)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01	70	70	70	100	100	100		1	mg/kg	-	49
Nickel (Ni)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01	25	25	25	50	50	50		1	mg/kg	-	26
Quecksilber (Hg)	FR	F5	DIN 22022-4: 2001-02			0,4	1	1	1		0,07	mg/kg	-	< 0,07
Zink (Zn)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01	200	200	200	400	400	400		1	mg/kg	-	60
Chrom (Cr)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01	70	70	70	90	90	90		1	mg/kg	-	26
Bor (B)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01								1	mg/kg	-	51
Mangan (Mn)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01								1	mg/kg	-	337
Silber (Ag)	FR	F5	DIN EN ISO 17294-2 (E29): 2017-01								5	mg/kg	-	< 5

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											Probenbezeichnung		Pyrolyseanlage PyroDry Pflanzenkohle	
				Vergleichswerte							Probennummer		123149317	
Parameter	**Lab.**	**Akkr.**	**Methode**	EBC-Futter-Plus	EBC-Futter	EBC-AgroBio	EBC-Agro	EBC-Urban	EBC-Gebrauchsmaterial	EBC-Rohstoff	**BG**	**Einheit**	**anl**	**wf**
Organ. Schadstoffe a. d. Toluolextrakt n. DIN EN 16181:2019-08(Extrakt.-verf. 2)														
Naphthalin	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	0,5
Acenaphthylen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Acenaphthen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Fluoren	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Phenanthren	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	0,1
Anthracen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Fluoranthen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Pyren	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Benzo[a]anthracen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Chrysen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Benzo[b]fluoranthen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Benzo[k]fluoranthen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Benzo[a]pyren	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Indeno[1,2,3-cd]pyren	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Dibenzo[a,h]anthracen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Benzo[ghi]perylen	FR	F5	DIN EN 16181:2019-08								0,1	mg/kg	-	< 0,1
Summe 8 EFSA-PAK exkl. BG	FR	F5	DIN EN 16181:2019-08	1	1	1	1	1	1	4		mg/kg	-	(n. b.) [1)]
Summe 16 EPA-PAK exkl. BG	FR	F5	DIN EN 16181:2019-08	6 [2)]		6 [2)]	6 [2)]					mg/kg	-	0,6
Benzo(e)pyren	FR	F5	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0,1	mg/kg	-	< 0,1
Benzo[j]fluoranthen	FR	F5	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0,1	mg/kg	-	< 0,1

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Erläuterungen

BG - Bestimmungsgrenze
anl - Anlieferungszustand
wf - wasserfreier Zustand
Lab. - Kürzel des durchführenden Labors
Akkr. - Akkreditierungskürzel des Prüflabors

Kommentare zu Ergebnissen
[1] nicht berechenbar

Die mit FR gekennzeichneten Parameter wurden von der Eurofins Umwelt Ost GmbH (Lindenstraße 11, Gewerbegebiet Freiberg Ost, Bobritzsch-Hilbersdorf) analysiert. Die Bestimmung der mit F5 gekennzeichneten Parameter ist nach DIN EN ISO/IEC 17025:2018 DAkkS D-PL-14081-01-00 akkreditiert.

Erläuterungen zu Vergleichswerten

Untersuchung nach Richtlinien für die nachhaltige Produktion von Pflanzenkohle - EBC, Version 10.3G – Stand 05.04.2023.

Ho,V / Hu,p: Brenn. bzw. Heizwert bei konstantem Volumen / Druck

AS: bezogen auf die Asche
OS: bezogen auf die Originalsubstanz

[2] Die sehr niedrigen PAK-Grenzwerte erlauben nur eine analytische Genauigkeit von 50% für den Grenzwert: "Summe 16 EPA-PAK" von 6 mg/kg, was eine Genauigkeit von ± 2,4 mg/kg (wf) bedeutet.

Bei der Darstellung von Vergleichswerten im Prüfbericht handelt es sich um eine Serviceleistung der EUROFINS UMWELT. Die zitierten Vergleichswerte (Grenz-, Richt- oder sonstige Zuordnungswerte) sind teilweise vereinfacht dargestellt und berücksichtigen nicht alle Kommentare, Nebenbestimmungen und/oder Ausnahmeregelungen des entsprechenden Regelwerkes.

Appendix B – Guarantee of origins for electricity consumption

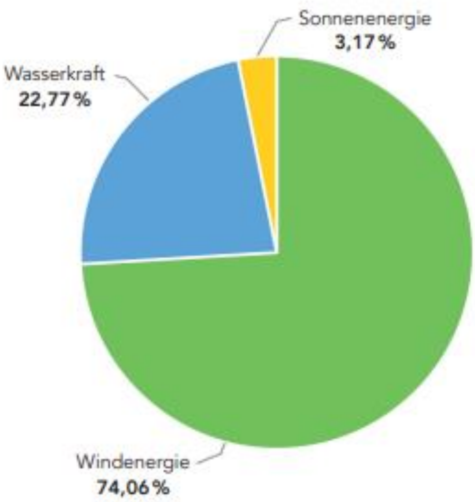
Burgenland Energie

Sekundäre (vollumfassende) Stromkennzeichnung

Gemäß § 78 und § 79 Elektrizitätswirtschafts- und -organisationsgesetz 2010 idF BGBl. I Nr. 5/2023 und Stromkennzeichnungsverordnung 2022 idF BGBl. II Nr. 48/2022 gibt BE Vertrieb GmbH & Co KG die sekundäre (vollumfassende) Stromkennzeichnung für den Zeitraum 1.1.2022 bis 31.12.2022 bekannt, auf Basis derer die gesamte Stromaufbringung der von BE Vertrieb GmbH & Co KG im Zeitraum 1.1.2022 bis 31.12.2022 an Endverbraucher gelieferten elektrischen Energie erzeugt wurde:

Versorgermix

Windenergie	74,06 %
Wasserkraft	22,77 %
Sonnenenergie	3,17 %
Summe	**100,00 %**



100 % der Herkunftsnachweise stammen aus Österreich.

Bei der Erzeugung des vorliegenden Versorgermixes sind keine Umweltauswirkungen gemäß § 5 der Stromkennzeichnungsverordnung 2022 idF BGBl. II Nr. 48/2022 angefallen.

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