Life cycle assessment of GRK Utajärvi biochar production and use for CORC calculation

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Glossary

CORC – CO2 Removal Certificate

ISO – International Organization for Standardization

LCA – Lice Cycle Assessment

LCI – Life Cycle Inventory

LCIA – Life Cyle Impact Assessment

tkm – ton kilometre, transport unit (1 ton x 1 km)

1. Introduction

This report presents the life cycle assessment (LCA) of the biochar produced by GRK in Utajärvi, Finland. The LCA follows the general principles defined in ISO 14040 and ISO 14044 standards, and the scope defined in sections 3 and 4 of Puro.Earth biochar methodology (edition 2022 version 2).

This assessment concerns the biochar production in GRK Utajärvi production plant, which was built in 2022-2023 and started its production in early 2023. The biochar produced in Utajärvi plant has already been used in construction projects in Finland and Sweden.

The study was commissioned by GRK, a construction group operating in Finland, Sweden, and Estonia. Besides biochar, it produces builds highways, tracks, and bridges and offers a wide range of circular economy services.

The life cycle assessment has been performed and the reports prepared by Heini Koutonen, MSc. in environmental economics, senior consultant at Nordic Offset Oy.

2. Goal and scope definition

2.1. Goal of the study

The goal of the study was to use life cycle assessment to reliably quantify the net CO2 removal (CORC) achieved over the time horizon of 100 years by the production of biochar.

The intended application and audience for the results is for external business-to-business communication. The results of the study can also be utilized internally for development purposes or marketing.

The LCA approach taken in this study is attributional LCA, which complies with the Puro Standard. The time period covered by the LCA is 1.5.2023-12.8.2023 because it is a well representative period of 3-months production capacity of the Utajärvi plant.

2.2. Scope of the study

2.2.1. Product-systems considered

This study assesses the actual biochar production in Utajärvi plant between May-August 2023, so no other scenarios were created. The product system studied in the assessment and its system boundary is presented in the flowchart below. The final product produced by the product system is biochar intended to be used as a substrate in construction projects.

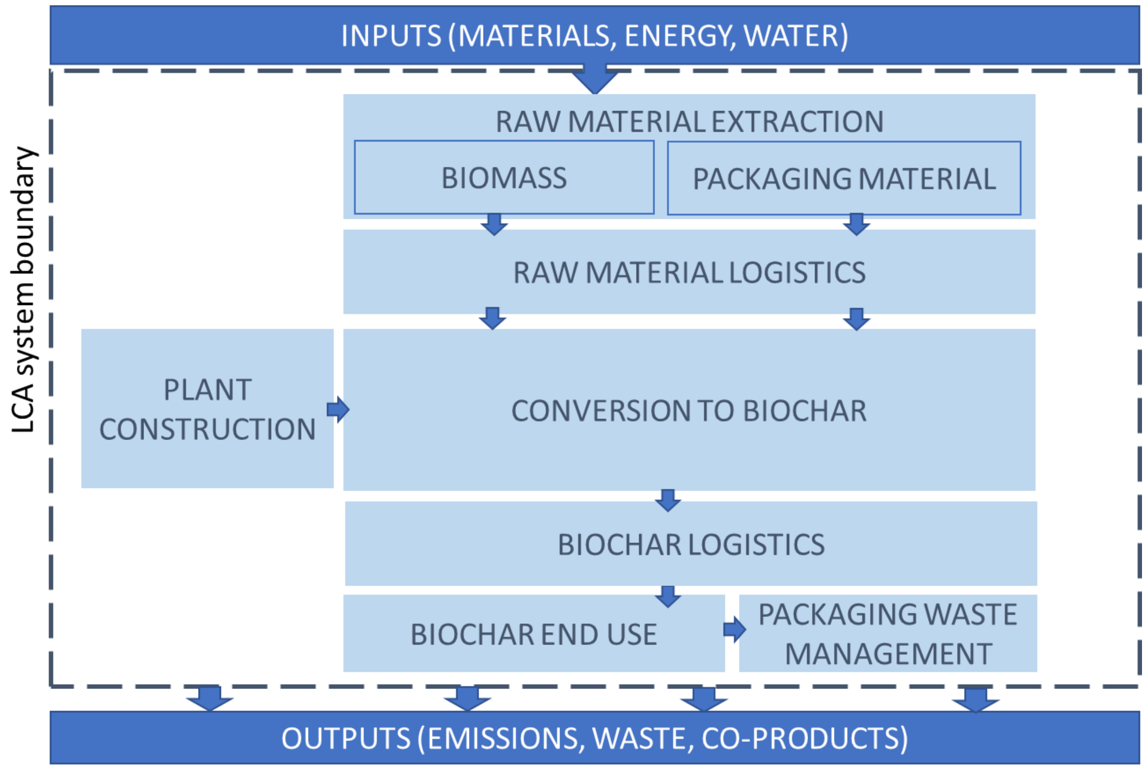

Figure 1. System boundaries flowchart.

2.2.2. Functional unit(s) and reference flow(s)

The functional unit in this study was 1 dry metric tonne of biochar produced and used in a mineral matrix or soil. The reference flow is then 1 dry metric tonne of biochar. The results were also scaled for the total production of the studied period, 132 tonnes of biochar.

2.2.3. Impact categories and impact assessment methods

This assessment regards only the climate change impact of biochar and no other environmental impact categories. A full LCA includes all relevant environmental impact categories, but for the purpose of certification by Puro only the climate change impact is required.

The climate impacts are assessed by using the Global Warming Potential (GWP) with a 100-year time horizon. The selected method for studying the climate change impact is CML2001 - Aug. 2016, Global Warming Potential (GWP 100 years). The method uses the baseline-characterization factors determined by the University of Leiden (2016).

2.2.4. System boundaries

The system boundary is set cradle-to-grave as shown in Figure 1 above. The system boundary includes all relevant life cycle stages: the emissions from supply of the biomass, from biomass conversion to biochar, and from biochar distribution and use. No relevant life cycle stages were omitted.

The representative geographical region for the system boundary is Finland (for biochar end use Finland and Sweden). This is reflected in data choices as far as possible, e.g. in chosen energy sources.

The system boundary and key assumptions related to life cycle stages are described below.

Raw material extraction: The biomass is wood chip (spruce) sourced from a nearby sawmill (Orasko), where it is a side stream of timber production. As packaging material, polypropylene bags and wooden pallets are used.

Raw material logistics: The biochar is transported 2 km from the sawmill to the pyrolysis plant. Packaging bags are transported by truck from 550 km distance and wooden pallets from 1 km distance. The distances and transport modes were accurately obtained from GRK.

Conversion to biochar: The construction of the biochar plant and related infrastructure is included in the system boundary. From the operation of the biochar plant, the electricity, heat, fuel and water usage are included. Energy types and consumption figures were accurately obtained from GRK.

Biochar logistics: The biochar is used as a substrate in construction projects, currently in Helsinki, Finland and Kalix, Sweden. The biochar logistics to the end use locations is considered based on actual transport distances and modes. The distances and transport modes were accurately obtained from GRK.

Biochar end use: The biochar is mixed on the use site with an excavator and its fuel use was included in the assessment. The fuel consumption of the excavator was calculated based on biochar density and the fuel consumption per tonne of handled material. The wooden pallet and polypropylene bag are by assumption sent to energy recovery.

2.2.5. Multi-functionality and allocation procedures

Allocation rules are used according to the ISO 14044:2006. Allocation is avoided when possible and when necessary, allocation is made based on physical shares (e.g. masses in kg). Allocation is required if the production process produces more than one product and the flows of materials, energy and waste cannot be separately measured for the studied product.

Avoiding allocation could not be avoided for electricity, heating, fuel and water consumption, as the information was only measured on factory level. The inputs were allocated per declared unit based on their physical volume (mass or litre).

The numerical values used for making the allocations is presented in the table below.

Table 1 Allocation of production inputs

	Total quantities
Total production volume on site	132 t
Electricity	39,8 MWh
Heating	240 MWh
Water consumption	450 m3
Fuel consumption	1500 l
	Allocated resources (per declared unit)
Electricity	301,7 kWh
Heating	1819 kWh
Water consumption	3,41 m3
Fuel consumption	11,4 l

Multi-functionality issues come into question only regarding the construction of the plant. In addition to biochar, GRK also produces pellets in Utajärvi and for example the storage hall is also used to store pellets. This is why some investment costs are allocated between biochar and pellet production according to estimates made by GRK (see table below).

Table 2 Multi-functionality of production facilities

	Total investment costs	Investment allocated to biochar	Investment allocated to pellet
Scale	Confidential (see Annex 1)	30 %	70 %
Pyrolysis equipment		100 %	-
Drying hall		50 %	50 %
Fence and barriers		100 %	-
Concrete works		50 %	50 %
Storage hall		30 %	70 %

There were no other multi-functionality issues identified in this study.

3. Life cycle inventory analysis

3.1. Software, databases, and other data sources

The life cycle inventory analysis (LCI) includes the collection of the data necessary to meet the goals of a LCA study as well as analysis of the life cycle inventory. The foreground data (activity data) concerning the production was collected directly from GRK by using an Excel form. The data represents the production of biochar in Utajärvi plant during 1.5.-12.8.2023 and its delivery and end use.

The following data inputs came from actual project measurements (by GRK unless stated otherwise) and thereby can be audited and verified:

- The amount of used raw material and packaging materials,
- Raw material transport distances and modes
- The amounts of used electricity, heat, fuel and water used in the production facility,
- Construction of the facilities:
    - the storage hall had an own LCA-study made for it
    - other construction was assessed via investment costs.
- The biochar carbon content was determined via laboratory analysis by Eurofins, as required in the Puro.Eath biochar methodology.
- Biochar transport distances and modes

Background data used for the LCA modelling was collected from the Sphera and Ecoinvent 3.9.1 databases. Generic datasets were chosen to represent the studied system as closely as possible. When supplier specific information was not available the information sources were chosen based on their technical and geographical representativeness. Only when country specific or European data has not been available, global level data been used. In situations where the available information was incomplete and estimates had to be made, assumptions were made based on the literature, average data, or generally accepted practice.

For the cost-based calculation of the plant construction, BEIS database with cost-based emission factors was used.

The modelling was made by using LCA for Experts software (former GaBi software), using the activity data collected by GRK and the life cycle inventory datasets provided by Sphera and Ecoinvent. The cost-based emission calculation was made separately in Excel and combined with the LCA-results in the results template provided by Puro.

3.2. Missing data disclosure

The electrical works and automation related to plant construction are excluded from the assessment due to lack of primary data.

No other process steps were excluded from the assessment.

3.3. Inventory data

3.3.1. Biomass supply

The biomass used in biochar production is wood chip (spruce) sourced from a nearby sawmill (Orasko), where it is a side stream of timber production. No supplier-specific emissions data was available from the sawmill, so the most representative generic dataset was used from Sphera. This wood chips data set covers all relevant process steps over the supply chain with a good overall data quality. The following background information related to the Sphera dataset describes what is included in the wood chips production:

> *The production process of wood starts with biological production of wood within forests. Depending on the wood species and the cultivation system 2,000 – 12,000 are planted per ha. As a rule of thumb pine trees are planted in higher numbers per ha then spruce trees. During the growing process, the wood stock underlies different management steps. The first management measure takes place in an age between 10 – 20 years where the young wood culture is trimmed. The number of trees per ha is reduced so that more light reaches the trees, which leads to better growing conditions. 10-15 years further the wood culture is thinned out again. After this first two management processes several smaller thinning processes are conducted to bring light into the culture and guarantee the best possible growing conditions of the most promising trees. After 80-120 years 200 – 400 trees are left on the area. Because of different forest production approaches the harvest can take place in different ways e.g. single tree removal, small group removal, harvesting with chainsaw or most often total clearance of the area via harvester. After the wood is harvested, trees are temporally stored in the forest and are then transported to sawmills. A mean transport distance of 125 km from forest to sawmill has been assumed.*
>
> *Sawmill data for European mills were compiled with data from Canada (Natural Resources Canada 2010), from the United States CORRIM (CORRIM 2012), AHEC (American Hardwood Export Council) and finally average data from participating Timber Trade Federation members from the UK were included. Information about the fuel consumption was also taken from the same sources and the average consumption was calculated as fuel use per m^3 of sawn wood. Splits of sawmill co-products (wood, woodchips, sawdust and bark) were gathered from the same sources.*
>
> *Sawmill inputs and outputs were allocated to individual sawmill products on the basis of price, with price ranges provided based on research into UK sawmills. Feedstock energy (the inherent energy contained in the wood) and sequestered carbon are allocated on a physical basis to the wood.*

As packaging material, polypropylene bags and wooden pallets are used. The bags are new and all emission from their production is included. The wooden pallets are retrieved from ending up in waste management, so their production is considered to have no environmental burden in this assessment.

The datasets used in the LCA are listed in the table below. All amounts are given per declared unit.

Table 3 Datasets used in modelling the biomass and packaging material supply

Raw material supply					
Input	**Dataset**	**Data representativeness**	**Database**	**Amount**	**Unit**
Biomass					
Wood chips	Wood chips spruce (10% water content) (Scandinavian silviculture)	Scandinavia, 2022	Sphera	1 543	kg
Packaging materials					
Plastic bags	Polypropylene fibres (PP)	Europe, 2022	Sphera	7,27	kg
Wooden pallets	Only transport is considered since the pallets are retrieved from ending up in waste management and thus considered to have no environmental burden.			47,7	kg

Table 4 Datasets used in modelling the raw material transport

Raw material transport					
Input	**Dataset**	**Data representativeness**	**Database**	**Amount**	**Unit**
Raw materials					
Wood chips	Truck, Euro 6 A-C, 26 - 28t gross weight / 18.4t payload capacity	Global, 2022	Sphera	2	km
	Diesel mix at filling station	Europe, 2019	Sphera	0,089	kg
Packaging materials					
Plastic bags	Truck, Euro 6 A-C, 26 - 28t gross weight / 18.4t payload capacity	Global, 2022	Sphera	550	km
	Diesel mix at filling station	Europe, 2019	Sphera	0,115	kg
Plastic bags	Truck, Euro 6 A-C, 26 - 28t gross weight / 18.4t payload capacity	Global, 2022	Sphera	1	km
	Diesel mix at filling station	Europe, 2019	Sphera	0,001	kg

Table 5 Vehicle unit emission factors

Vehicle unit emission factors	**Value**	**Data quality**
Specific transport emissions, CO_2 emissions kg CO_2 ekv. /tn x km	0,100 kg CO2e /tkm	Truck, Euro 6 A-C, 26 - 28t gross weight / 18.4t payload capacity
Capacity utilisation (including empty returns)	55 %	Truck average default capacity utilisation

3.3.2. Biochar production

In addition to the operative activities of biochar production, the construction of the biochar plant and related infrastructure is included in the system boundary of this assessment.

The production site has the pyrolysis plant and a storage building. The estimated lengths of their use phase are presented in the table below. All emissions from construction are allocated for the whole use phase based on the estimated months in use.

Table 6 Use phase length for the buildings

	Pyrolysis plant	Storage building	Unit
Use phase length	15	50	years
	180	600	months

The storage hall had an own LCA-study made for it by Best-Hall and OneClick LCA (see Annex 2). According to GRK, about 70 % of the capacity of the storage building is used for pellets and only 30 % for wood chips/biochar, so the emissions of the storage hall construction were allocated based on these figures.

Table 7 Results of the separate Life Cycle Assessment made for the storage building. Source: Best-Hall / OneClick LCA 2023.

	GWP fossil	Unit
Emissions from storage hall construction (Best-Hall / Oneclick LCA 2023)	219 131	kg CO2e
Allocated emissions for biochar (30 % of total)	65 739	kg CO2e
Emissions per year	1 315	kg CO2e
Emissions per month	110	kg CO2e

The emissions from other investments related to the plant construction were calculated based on their cost in euros provided by GRK. The machines and buildings and the datasets used in the calculation are listed in the table below. The electrical works and automation is excluded from the assessment due to lack of primary data. All cost-based emission factors have been inflation corrected to better reflect the cost level in 2023.

Table 8 Datasets used in modelling the plant construction

	Item	Dataset	Data representativeness	Database	Amount	Unit
Machines	Scale	Machinery and equipment	Europe, 2011	BEIS	Confidential (see Annex 1)	€
	Pyrolysis equipment	Machinery and equipment	Europe, 2011	BEIS		€
Buildings	Drying hall	Construction	Europe, 2011	BEIS		€
	Fence and barriers	Construction	Europe, 2011	BEIS		€
	Concrete works	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster	Europe, 2011	BEIS		€
	Storage hall	Own separate LCA-study made for the storage hall.				

Similarly to the storage hall, the scale and the drying hall are also used for pellet production, so 30 % of the scale investment and 50 % of the drying hall investment is allocated to biochar, the rest for the pellets according to the estimates by GRK.

The operative emissions from conversion of biomass to biochar include the consumed electricity, heat, fuel and water usage. The electricity use was modelled supplier-specifically according the guarantee of origin provided by VENI Energia. The different energy sources used in the electricity production in 2022 were hydro power (51,7 %), biomass (25,7 %) wind power (15,8 %) and solar power (6,8 %). The distribution for the year 2023 is not yet known, because the guarantees of origin will not be offset against actual consumption until 2024, when the final distribution will be determined. The guarantee of origin document is available in Annex 3.

For heat production the plant uses wood chips acquired from the nearby sawmill. Additionally operational emissions include fuel use (Neste MY renewable diesel was used) and water consumption.

No waste is generated during the biochar production process.

The datasets used in the LCA are listed in the table below. All amounts are given per declared unit.

Table 9 Datasets used in modelling operational biochar production

Biochar production					
Input	**Dataset**	**Data representativeness**	**Database**	**Amount**	**Unit**
Production process					
Electricity: VENI Energia mix	Electricity from hydro power	Finland, 2019	Sphera	156,0	kWh
	Electricity from wind power	Finland, 2019	Sphera	47,7	kWh
	Electricity from photovoltaic	Finland, 2019	Sphera	20,5	kWh
	Electricity from biomass (solid)	Finland, 2019	Sphera	77,5	kWh
Heat	Thermal energy from biomass (solid)	Finland, 2019	Sphera	240,1	kWh
Fuel	Neste MY diesel	Finland, 2017	Grönman et al. 2018	11,36	L
Water	Tap water from groundwater	Finland, 2022	Sphera	3,41	m3

The facility uses purchased electricity, and the supplier-specific production profiles was used in the LCA modelling. For heating, the plant uses 100 % biomass (wood chips). No assumptions had to be made regarding the energy-related data. The unit emission factors of the used energy sources can be seen below.

Table 10 Unit emission factors for used electricity and heat

Parameter	Unit emissions	Data quality
Electricity information and CO_2 emission	0,016 $kgCO_2e$ /kWh	Supplier-specific information from VENI Energia: hydro power (51,7 %), biomass (25,7 %) wind power (15,8 %) and solar power (6,8 %)
Heat information and CO_2 emission	0,007 $kgCO_2e$ /kWh	Thermal energy from solid biomass, Finland 2019, Sphera database.

3.3.3. Biochar end use

The biochar is used as a substrate in construction projects, currently in Helsinki, Finland and Kalix, Sweden. Of the produced biochar 44 % was distributed to Finland and 40 % to Sweden. The remaining 15 % was kept in storage.

The biochar logistics to the end use locations is considered based on actual transport distances and modes. The distances and transport modes were accurately obtained from GRK.

The datasets used in the LCA are listed below. All amounts are given per declared unit.

Table 11 Datasets used in modelling biochar distribution

Biochar distribution					
Input	**Dataset**	**Data representativeness**	**Database**	**Amount**	**Unit**
Transport to Helsinki	Truck-trailer, Euro 6 A-C, 34 - 40t gross weight / 27t payload capacity	Global, 2022	Sphera	209	km
	Diesel mix at filling station	Europe, 2019	Sphera	1,9	kg
Transport to Sweden	Truck-trailer, Euro 6 A-C, 34 - 40t gross weight / 27t payload capacity	Global, 2022	Sphera	601	km
	Diesel mix at filling station	Europe, 2019	Sphera	5,93	kg

Table 12 Vehicle unit emission factors

Parameter	Quantity	Data quality
Transport, distance	209 or 601 km	Primary data
Specific emissions, type of vehicle used for transport	0,074 kg CO_2e /tkm	Truck-trailer, Euro 6 A-C, 34 - 40t gross weight / 27t payload capacity
Capacity utilization	Truck average capacity utilisation default 61 %	

On the end use site the biochar is mixed and spread with an excavator and its fuel use was included in the assessment. The fuel consumption of the excavator was calculated based on biochar density and the fuel consumption per tonne of handled material. The wooden pallet and polypropylene bag are by conservative assumption sent to energy recovery.

The datasets used in the LCA are listed below. All amounts are given per declared unit.

Table 13 Datasets used in modelling biochar end use

Biochar end use					
Input	**Dataset**	**Data representativeness**	**Database**	**Amount**	**Unit**
Biochar spreading					
Biochar use in Sweden	diesel, burned in building machine	Global, 2022	Ecoinvent 3.9.1	6,76	MJ
Biochar use in Helsinki	diesel, burned in building machine	Global, 2022	Ecoinvent 3.9.1	7,38	MJ
Packaging waste management					
Sweden	Polypropylene (PP) in waste incineration plant	Europe, 2022	Sphera	6,4	kg
	Untreated wood in waste incineration plant	Europe, 2022	Sphera	21	kg
Finland	Polypropylene (PP) in waste incineration plant	Europe, 2022	Sphera	6,4	kg
	Untreated wood in waste incineration plant	Europe, 2022	Sphera	21	kg

3.3.4. Biochar carbon content

To be able to compute the net CO2 removal, the carbon content of the biochar was determined in a laboratory analysis (Eurofins). Once the laboratory results for biochar dry mass, organic carbon content, hydrogen content were available, the data was input in the Puro Biochar calculator for biochar carbon storage. The laboratory analysis results can be seen in Annex 4. The laboratory analysis also produced other results that were not used in this LCA.

The soil temperature selected for the calculation of the biochar carbon sequestration represents the average soil temperature in boreal forest areas as determined by Lembrechts et al. (2021).

A picture of the calculator for biochar carbon storage with all the input values can be seen below.

A. Input data [change with your own values]

Parameter name	Value	Unit	Comment
Organic carbon content of biochar	84,90 %	%, dry weight	As determined by laboratory analysis.
Hydrogen content of biochar	2,20 %	%, dry weight	As determined by laboratory analysis.
Annual average soil temperature at site of biochar use	1,7	°C	Default value: 14.9°C (global average for cropland). Value can be in the range 0 to 25°C depending on location. It can be assumed to be equal to the annual average surface air temperature at the location. Alternatively, the map referenced in the methodology can be used (cf. comment).
Time horizon of sequestration	100	years	Default value: 100 years. Can be set to longer time frames if needed.
Biochar production over reporting period	132	t, dry weight	To be estimated by CORC supplier based on size of biochar production facility.

B. Intermediary calculations [no change allowed]

Parameter name	Value	Unit	Comment
Hydrogen to organic carbon molar ratio	0,3110	mol / mol	Calculated from input data (must be less than 0,7)
Slope of linear regression	-0,309	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)
Intercept of linear regression	1,101	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)
Coefficient of regression of linear regression	0,271	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)

C. Output data [no change allowed]

Parameter name	Value	Unit	Comment
Permanence factor $F_p^{TH,Ts}$	100,00 %	%	At given soil temperature, and time horizon selected
Carbon dioxide stored per tonne of biochar	3,113	$t\ CO_2$ / t dry biochar	At given soil temperature, and time horizon selected
Carbon dioxide stored over reporting period (E_{stored})	410,92	$t\ CO_2$	At given soil temperature, and time horizon selected, for given production period

Figure 2 Biochar carbon storage determination

4. Life cycle impact assessment and interpretation

In life cycle impact assessment, the calculation methodology followed the overall equation for the quantification of CO2 removal defined by Puro.earth (see figure below). The equation is made of four terms: the amount of CORCs supplied is equal to the amount of carbon dioxide sequestered by the biochar minus life-cycle emissions from the pyrolysis process, the biomass provision, and the biochar use.

$$CORCs = E_{stored} - E_{biomass} - E_{production} - E_{use}$$

	$CORCs$	E_{stored}	$E_{biomass}$	$E_{production}$	E_{use}
Description	Amount of net CO_2-eq removed over 100-year period by the biochar production activity	Amount of CO_2 sequestered over a 100-year time horizon by the amount of biochar produced over the reporting period.	Life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes.	Life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility.	Life cycle greenhouse gas emissions arising from the use of the biochar, including its distribution up to the point of final use.
Unit	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq

Figure 3 Equation to calculate the amount of CORCs supplied by the biochar production.

The life cycle inventory of these four terms was presented in the above chapters 3.3.1 – 3.3.4.

The life cycle impact assessment was made based on the data collection described in the previous chapter. The modelling was made by using LCA for Experts software (former GaBi software). Quantitative data on input and output flows, transport modes and distances were entered into the program. The software automatically calculates the environmental impact category results based on the entered data. A snip of the LCA model can be seen in Annex 5.

The emissions from construction were calculated separately in an Excel-file due to different form of activity data (€ amounts) and background data (cost-based emission factors).

The climate impact results from LCA for Experts -software and the separate Excel for construction emissions were combined in the Puro LCA results Excel file.

The results per functional unit (1 tonne of biochar produced and used) and for the whole reporting period are presented in the table below. Level-1 categories are set by the Puro biochar methodology and Level-2 categories describe the more detailed results from the biochar production phases. The Level-1 contributions are meant to be publicly shared in the Puro registry. The Level-2 contributions break down each Level-1 category in sub-stages, providing more details about the actual activities that cause the emissions.

Table 14 Life cycle impact assessment results for GRK biochar production

		CORCs per FU 2,79	Total (CORCs) 367,8
Contribution levels (life cycle stages & sub-stages)		**Results per functional unit (1 tonne of biochar produced)**	**Results per year or reporting period**
Level-1	**Level-2**	**Climate impact in kg CO2-eq**	**Climate impact in kg CO2-eq**
$E_{biomass}$	Wood chips production	**15,99**	**2 111**
$E_{biomass}$	Transport to plant	**0,31**	**41**
$E_{production}$	Pyrolysis equipment	**182,85**	**24 136**
$E_{production}$	Other infrastructure	**19,13**	**2525**
$E_{production}$	Electricity usage on site	**4,71**	**622**
$E_{production}$	Heating on site	**12,75**	**1 683**
$E_{production}$	Fuel usage on site	**4,02**	**531**
$E_{production}$	Water usage on site	**0,24**	**32**
$E_{production}$	Handling of biochar and bagging	**16,23**	**2 142**
E_{use}	Transport to end-user	**27,52**	**3 633**
E_{use}	Biochar mixing and spreading	**1,40**	**185**
E_{use}	Packaging material recycling	**41,22**	**5 441**
E_{stored}	Biochar carbon storage	**-3113,00**	**-410 916**

The results show that the total emissions from the supply-chain are 326 kg CO2e per 1 tonne of biochar and 43 081 kg CO2e for the whole reporting period.

The biochar carbon storage (E stored) is 3,113 tonnes per tonne of biochar, which is in line with the average biochar carbon content of 3-3,5 tonnes per tonne.

Thus, the gross amount CO2 removed for 100 years is 2,79 tonnes per dry metric tonne of biochar and 368 tonnes for the whole reporting period. The total emissions from the supply chain are only 10,5 % of the biochar carbon storage. This is illustrated in the figures below.

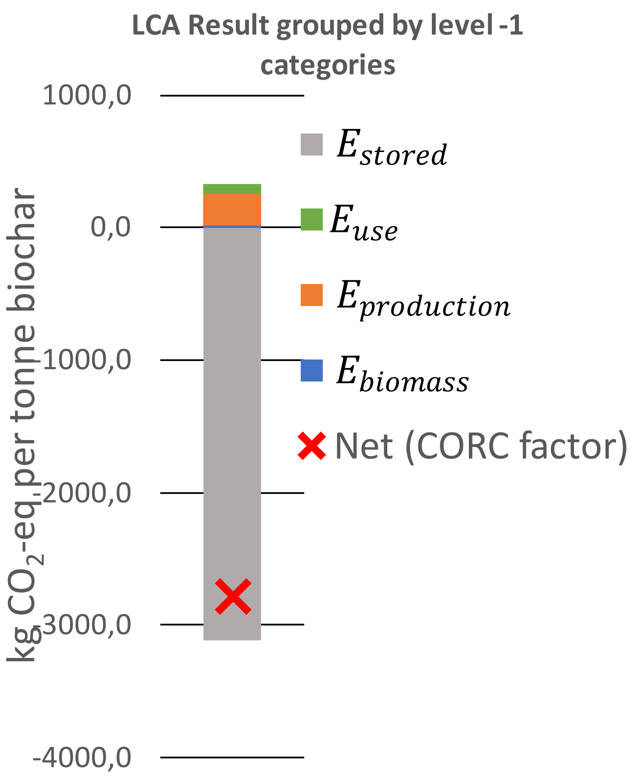

Figure 4. The LCA results of GRK biochar (kg CO2e per tonne biochar).

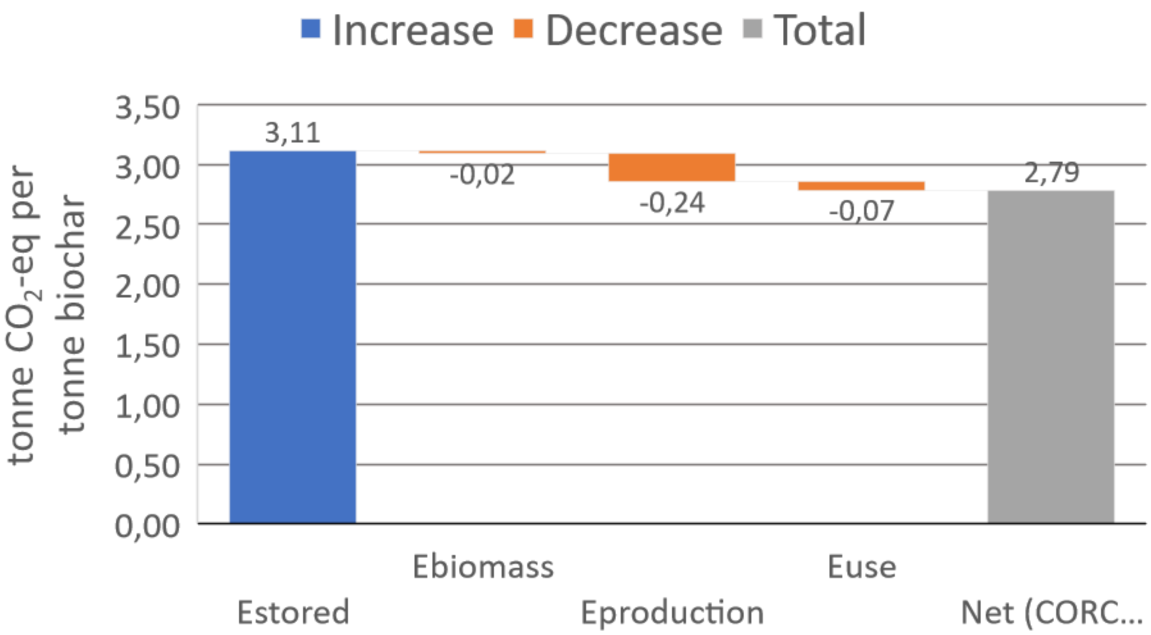

Figure 5 Climate impact of GRK biochar (tonne CO2e per tonne biochar)

The contribution of different greenhouse gases was not analysed, because not all impact assessment data was available on that level (e.g. construction of the facilities) and furthermore because that format of reporting is optional in Puro methodology.

5. Discussion, conclusions, and recommendations

In this study, the net CO2 removal of the GRK biochar was successfully quantified. It can be concluded that the GRK biochar acts as a carbon storage and can be used in CO2 removal applications. The result seems reasonable and justified, and it can be interpreted that the LCI and LCIA results are well aligned with each other and can be explained.

In this study, as in all LCA studies, many sources of uncertainty exist. In this study, it is justified to assume that the highest uncertainties arise from the secondary data applied. The measured and calculated primary data gathered from the production plant and supply chain of the studied product is at high priority, and such data has therefore been used in the study always when available. Primary data are precise, but secondary data, such as data from the databases, may contain broad uncertainties.

Some identified limitations concerning each term of the CORC calculation are:

- E_{stored}: No remarkable limitations were identified since the carbon content calculation is based on laboratory analysis results and the calculation template provided by Puro. One factor that could still be specified, would be to use the mean annual soil temperature in the exact biochar use locations in Southern Finland and Northern Sweden to get a more accurate biochar carbon storage figure for those locations. The result presented above uses the mean soil temperature in boreal forest zones so it is not limited to the exact locations and can thus be applied to other potential future use locations in the boreal climate zone.

- $E_{biomass}$: No remarkable limitations are related to biomass supply. Primary data was used for the amount and transport details of biomass supply from the nearby sawmill and the impact data set chosen for the wood chip production is well representative technologically and geographically.

- $E_{production}$: The biggest limitation regarding biochar production was the construction emissions calculation based on cost-based primary data and background data. The emissions of storage hall construction were known accurately, since it was the only building that had an own life cycle assessment made for it.

- E_{use}: The assumption that the wooden pallet and polypropylene bag sent to energy recovery is a limitation, since the materials could potentially be recycled as material, but this is not known, so a conservative assumption was chosen. No remarkable limitations are related to biochar transport to use location. The fuel use in biochar spreading was estimated based on calculation, which sets a minor limitation compared to if measured fuel consumption was available, but its significance in the results is marginal.

Of all the input parameters, the construction data would be key to follow-up with actual project data. If for example GRK would invest in another production plant, it is recommended to perform own life cycle assessments for the buildings. Other input parameters in this study were already well representative.

The LCIA results presented in this study are calculated based on a 3,5-month production period, which is another source of uncertainty. It is recommended that the calculation be renewed when data from a longer (e.g. one year) production period comes available.

6. References

University of Leiden (2016). CML-IA Characterisation Factors. CML - Department of Industrial Ecology. Saatavilla: https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors

Eurofins (2023). Laboratory analysis, report number AR-23-FR-050851-01

Grönman, K., Pajula, T., Sillman, J., Leino, M., Vatanen, S., Kasurinen, H., ... & Soukka, R. (2019). Carbon handprint–An approach to assess the positive climate impacts of products demonstrated via renewable diesel case. Journal of Cleaner Production, 206, 1059-1072.

ISO 14040:2006 + A1:2020 Environmental management - Life cycle assessment - Principles and framework

ISO 14044:2006 + A1:2018 + A2:2020 Environmental management. Life cycle assessment. Requirements and guidelines.

Lembrechts, J. J., van den Hoogen, J., Aalto, J., Ashcroft, M. B., De Frenne, P., Kemppinen, J., ... & Hik, D. S. (2022). Global maps of soil temperature. Global Change Biology, 28(9), 3110-3144.

OneClick LCA / Best-Hall (2023): Rakennuksen elinkaaren hiilijalanjälki standardin EN 15978 mukaan

Puro.earth (2022). Biochar methodology, Edition 2022 version 2.

7. Appendix

ANNEX 1 (Confidential): Investment to plant construction and its allocation to biochar and pellet production

ANNEX 2: Results of the separate Life Cycle Assessment of the storage building.

ANNEX 3: Guarantee of Origin of purchased electricity.

ANNEX 4: Laboratory analysis results used in the biochar carbon content calculation.

ANNEX 5: Life cycle model in LCA for Experts software

ANNEX 2. Results of the separate Life Cycle Assessment of the storage building. Source: OneClick LCA / Best-Hall (2023): Rakennuksen elinkaaren hiilijalanjälki standardin EN 15978 mukaan.

3. Tulokset: Rakennuksen elinkaaren hiilijalanjälki standardin EN 15978 mukaan

Alla olevassa taulukossa on esitetty kokonaishiilijalanjälkeen vaikuttavat osa-alueet. Tässä projektissa esimerkiksi rakentamisvaiheesta muodostuu noin 3 tonnin hiilidioksidipäästöt. Laskennassa on huomioitu valmistus-, kuljetus- ja rakennusvaiheiden lisäksi huippuimurin vuosittainen energiankulutus. Suurin päästöjen aiheuttaja näistä on kuitenkin valmistusvaihe johtuen materiaalien hiilijalanjäljestä. Kuljetuksen ja syntyvien jätteiden aiheuttamat päästöt ovat pienet, koska materiaalien kuljetusmatkat ovat lyhyet ja teräksen hyötykäyttöprosentti korkea.

Entity users	**Project name**	**Design name**	**Indicator name**
Jenny Ronnkvist	GRK Road Oy	2 - GRK Road - Hiilijalanjälki	Level(s) elinkaaren hiilijalanjälki (FI)
Osio	**Osa-alue**	**Ilmaston lämpeneminen kg CO_2e**	**Biogeeninen hiili kg CO_2e bio**
A1-A3	Tuotevaihe	**182029.75**	**71.12**
A4	Kuljetus rakennustyömaalle	**1578.7**	
A5	Rakentamisvaihe	**2757.54**	
B1	Käyttövaihe		
B1-a	Kylmäaineen vuotaminen vuosittain		
B1-b	Kylmäainehävikki, laitteiden vaihto		
B1-c	Kylmäainehävikki, laitteiden käyttöiän päättyminen		
B1-d	Sementtipohjaisten tuotteiden hiilinielut		
B1-e	Kasvillisuuden hiilidioksidin poistaminen		
B4-B5	Osien vaihto ja peruskorjaukset	**16351.06**	
B6	Energiankulutus	**10028.38**	
B7	Veden käyttö		
C1-C4	Purkaminen	**6386.03**	
D	Asennetut materiaalit - hyöty	**-24147.62**	

Kuva 4. Hiilijalanjäljen muodostavat osa-alueet ja materiaalit (Lähde: OneClick LCA).

ANNEX 3. Guarantee of Origin of purchased electricity

Alkuperätakuutodistus

VENI Energia takaa tällä todistuksella, että

GRK Suomi Oy

hankkima sähkö on alkuperätakuumerkittyä 100 % uusiutuvaa energiaa.

Todistuksen tyyppi	**Alkuperätakuu**
Ajanjakso	**2023**
Alkuperä	**Eurooppa**
Tuotantomuoto	**Vesi, Tuuli, Aurinko, Bio, Geoterminen***

*Lopullinen tuotantomuotojen jakauma määräytyy kun alkuperätakuut kuoletetaan toteutunutta kulutusta vastaavasti

Ilkka Salonen
Country Director

VENI Energia

ANNEX 4. Laboratory analysis results used in the biochar carbon content calculation

eurofins | Umwelt

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Parameter	Lab	Accr.	Method	1) EBC-FeedPlus	2) EBC-Feed	3) EBC-Agro Organic	4) EBC-Agro	5) EBC-Urban	6) EBC-Consumer Materials	7) EBC-Basic Materials	LOQ	Unit		ar	db
				Limit values							Description		biochar		
											Sample number		123138137		
Biochar properties															
Bulk density < 3 mm	FR		based on VDLUFA-Methode A 13.2.1									kg/m³	-	-	161
water holding capacity (WHC) < 2 mm	FR		DIN EN ISO 14238, A: 2014-03									%	-	-	247.5
Moisture	FR	F5	DIN 51718: 2002-06								0.1	% (w/w)	-	26.3	-
Ash content (550°C)	FR	F5	DIN 51719: 1997-07								0.1	% (w/w)	-	5.7	7.7
Total carbon	FR	F5	DIN 51732: 2014-07								0.2	% (w/w)	-	62.7	85.1
carbon (organic)	FR		Calculation									% (w/w)	-	62.6	84.9
Hydrogen	FR	F5	DIN 51732: 2014-07								0.1	% (w/w)	-	1.6	2.2
Total nitrogen	FR	F5	DIN 51732: 2014-07								0.05	% (w/w)	-	0.34	0.46
Sulphur (S), total	FR	F5	DIN 51724-3: 2012-07								0.03	% (w/w)	-	< 0.03	< 0.03
Oxygen	FR	F5	DIN 51733: 2016-04									% (w/w)	-	3.7	5.0
Total inorganic carbon (TIC)	FR	F5	DIN 51726: 2004-06								0.1	% (w/w)	-	0.1	0.2
carbonate-CO2	FR	F5	DIN 51726: 2004-06								0.4	% (w/w)	-	0.5	0.7
H/C ratio (molar)	FR		Calculation										-	0.31	0.31
H/Corg ratio (molar)	FR		Calculation	< 0.4	< 0.4	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7			-	0.31	0.31
O/C ratio (molar)	FR		Calculation										-	0.044	0.044
Volatile Compounds	FR	F5	DIN 51720: 2001-03								0.2	% (w/w)	-	9.2	12.5
pH in CaCl2	FR		DIN ISO 10390: 2005-12										-	8.3	-
salt content	FR		BGK III. C2: 2006-09								0.005	g/kg	-	0.496	-
salt content	FR		BGK III. C2: 2006-09								0.005	g/l	-	0.080	-
Conductivity at 1,2 t pressure	FR		Internal Method SAA-H-LI-Pflanzenkohle.040								0.01	mS/cm	-	-	0.02
Conductivity at 2 t pressure	FR		Internal Method SAA-H-LI-Pflanzenkohle.040								0.01	mS/cm	-	-	0.05
Conductivity at 3 t pressure	FR		Internal Method SAA-H-LI-Pflanzenkohle.040								0.01	mS/cm	-	-	0.07

ANNEX 5. Life cycle model in LCA for Experts software