Position paper

Overall evaluation of 'Ökologische Klärschlammtrocknung Offenhausen GmbH' regarding the greenhouse gas (GHG) saving potential incl. the production and application of biochar.

CARBON STANDARDS international

NGE MATERIAL MORPHING TECHNOLOGY

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1. Preamble

Currently, pyrolysis plants are considered as stand-alone solutions to produce biochar from woody biomass. Based on the stored carbon in the product, the carbon sink potential (carbon sink potential) is calculated and certified, for example via EBC carbon sink standard. The holistic consideration of the CO_2 saving potential of sites and plants, which is realized by the systematic linking of different technologies, is unavoidable in today's world. Thus, in the future, a plant / site must be evaluated according to the CO_2 saving potential and the active CO_2 storage of their processes.

This position paper focuses on the CO_2 saving potential of a pyrolysis project, which extends beyond the carbon sink potential of the produced biochar. Special attention is paid to the saving of fossil energy by the provision of waste heat and thus points out the currently still little considered aspect of CO_2 saving.

The 'Ökologische Klärschlammtrocknung Offenhausen GmbH' (ÖKT), located near Nürnberg, is used as a case study. The plant, consisting of a biogas plant and a sewage sludge dryer, was extended by a pyrolysis plant in 2022. The CO_2 reduction potentials are made up of the following sub-topics:

- Sewage sludge drying: The drying of sewage sludge makes it possible to reduce the amount of transport on site and thus saves on truck journeys. The sewage sludge is no longer applied to agricultural fields – this avoids methane emissions.

- Provision of climate-neutral waste heat for drying sewage sludge from the biogas plant or pyrolysis. The thermal use of liquid gas for sewage sludge drying has been replaced.

- Production and use of biochar: The production of biochar converts carbon into a stable form. The use of biochar in soil-related applications thus creates a long-term carbon sink.

The overall consideration of these greenhouse gas reductions represents the CO_2 reduction potential of the entire pyrolysis project at ÖKT. The carbon sink of the biochar, which covers part of the reduction potential, can also be used to generate tradable CO_2 certificates. For the certification of the carbon sink, a precise calculation of the data within the framework of a standard, as well as a check by a neutral verification body is necessary. The EBC C-sink standard is recommended for this purpose.

The CO_2 reductions calculated here from the avoidance of direct application of the sewage sludge, from the reduction of truck transports and from the savings of fossil energy are based on hypotheses and are associated with uncertainties. Accordingly, the use of these CO_2 reductions as a basis for certificate trading in the free market is not possible.

The consideration of this reduction potential could find its way into future European regulations. The findings from this paper can also be used in the project planning of pyrolysis plants at other locations to evaluate their climate-neutral or climate-positive effect.

One of the focuses of interest of this paper is to outline the incentives for investing in pyrolysis plants. In this context, the EU Taxonomy Regulation has to be taken into account, which creates rules and framework conditions for sustainable economic activity in order to meet the objectives of the European Green Deal while ensuring a competitive equality for all companies. The regulation includes a framework for measuring the environmental sustainability of an investment and focuses on six environmental aspects [8]:

- Climate change mitigation
- Climate change adaptation
- Sustainable use and protection of water and marine resources
- Transition to a circular economy
- Pollution prevention and control
- Protection and restoration of biodiversity and ecosystems

2. Background and system boundary

Based on the agricultural business, the first biogas plant was built in 2011 for the utilization of landscape maintenance material, manure (horses/cattle/sheep) and silage corn. Due to the expansion of the biogas plant in 2012 and 2018, a capacity of 900 kW (of which 500 kW electric) can currently be tapped via a combined heat and power plant (CHP, see Figure 1).

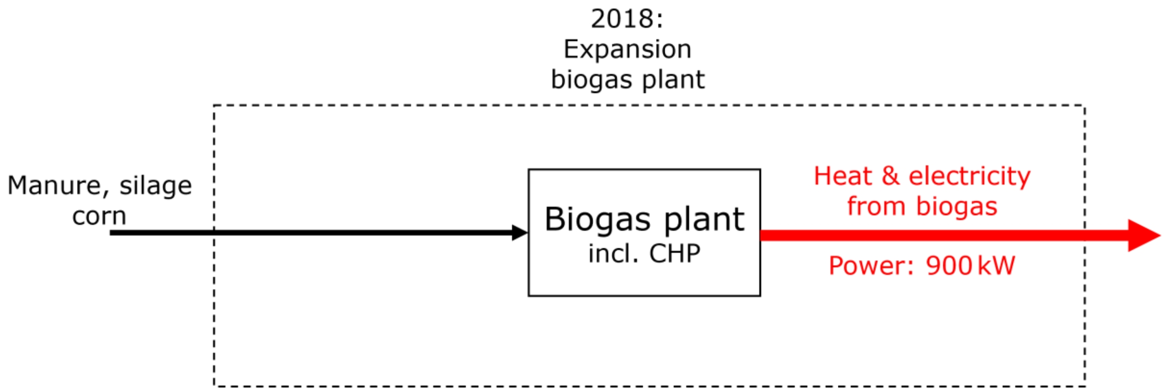

Figure 1: Flowchart of the entire plant 2018: Due to the expansion of the biogas plant, heat and electricity with a capacity of 900 kW can now be provided.

With the foundation of the 'Ökologische Klärschlammtrocknung Offenhausen (ÖKT) GmbH' in 2019, the company specialized in the drying of municipal sewage sludge (approx. 6'000 t of dewatered sewage sludge per year with 26 % DM). The necessary heat or drying air for the dryer system is provided by the exhaust gas of the CHP unit (see Figure 2).

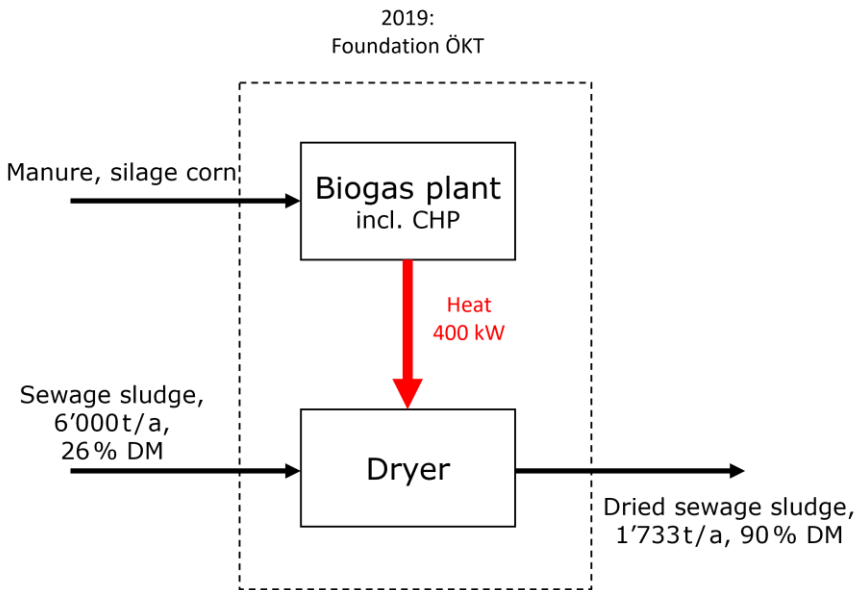

Figure 2: Flowchart of the entire plant in 2019: With the establishment of ÖKT, the biogas plant was expanded to include a sewage sludge dryer. The heat required for this is provided by the biogas plant's CHP unit.

Figure 3: Ökologische Klärschlammtrocknung Offenhausen GmbH

In 2020, there was an expansion and extension of the ÖKT. By installing two additional dryer systems, the current maximum annual capacity of 18’000 t could be reached (see Figure 4). In addition to using the waste heat from the CHP unit, liquefied gas (LNG) now had to be used as a heat source. However, the use of liquefied gas was always an issue. From an ecological point of view, an alternative had to be found.

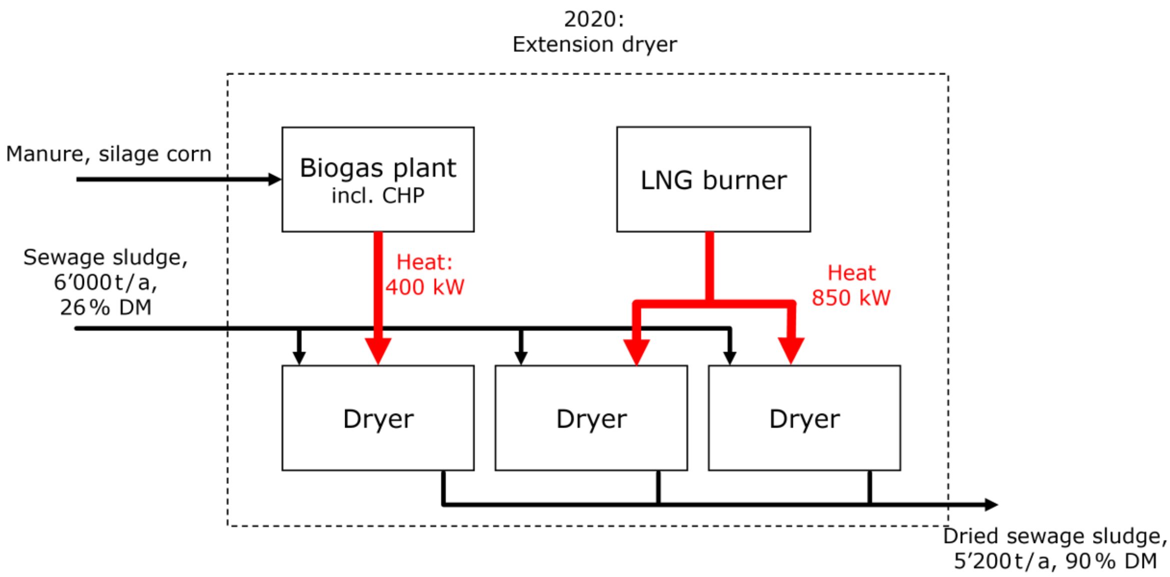

Figure 4: Flowchart of the entire 2020 plant: With the expansion of the dryer system, additional heat now had to be provided by means of liquefied gas.

In addition to the integration of the biogas plant into ÖKT in 2022, the plant was also expanded by two pyrolysis plants for the sustainable provision of waste heat for the dryers and the simultaneous production of biochar from wood chips.

Currently (Q4 2023), two pyrolysis plants with a total capacity of 850 kW are running for the complete replacement of natural gas in the drying operation (see Figure 5 and Figure 6). Waste heat from the CHP unit is used to dry the wood chips before pyrolysis.

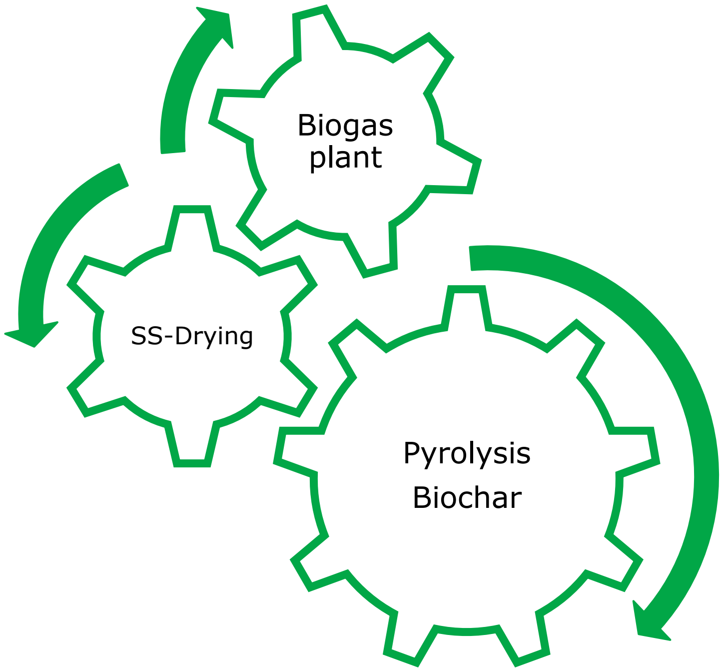

Figure 5: Interlocking of different technologies for maximizing CO_2 reduction potentials.

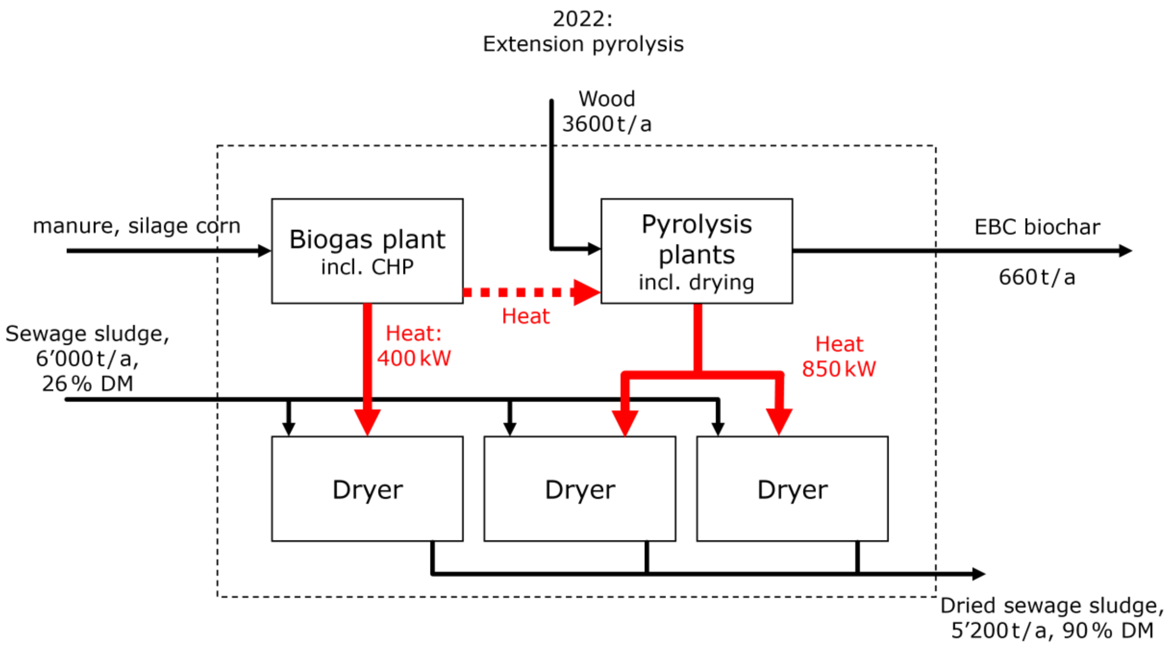

Figure 6: Flowchart total plant 2022: Extension of the ÖKT by 2 pyrolysis plants. The fossil heat from the combustion of the liquefied gas has now been replaced with the renewable alternative from pyrolysis. Pyrolysis simultaneously produces biochar, thus creating a long-term carbon storage.

3. Replacing fossil fuels with waste heat from the pyrolysis plant

By using the two pyrolysis plants since the end of 2022, a power of 850 kW can be provided for drying the sewage sludge. Before the installation of the pyrolysis reactors, this heat had to be covered by liquid gas and the CHP of the biogas plant to dry the same amount of sewage sludge (see Figure 4).

An alternative to drying the sewage sludge is the direct use of the sewage sludge by direct application or composting. However, this use will be banned in Germany and Austria by the end of this decade.
In addition to the problem of spreading pollutants such as microplastics, drug residues, etc., material sewage sludge utilization is also to be classified as a more climate-damaging alternative due to methane emissions. If 18'000 t sewage sludge (26 % DM) were applied to the field annually, CO_2e emissions of **19'081 t CO_2e per year** are to be expected based on the calculation method of the Austrian Federal Environment Agency [3] . This enormous GHG emission potential is thus another important point why sewage sludge should be submitted to immediate thermal utilization.

Table 1: GHG emissions from the discharge of sewage sludge onto agricultural fields

Amount of sewage sludge, 26% DM	18’000	t / a
Amount of sewage sludge, converted to 34% DM	13’765	t /a
Methane formation from sewage sludge (34% DM) [3]	69.05	m^3/ t
Density methane	0.717	kg / m^3
Methane emissions after discharge of sewage sludge	681	t CH_4 / a
GHG emissions after discharge of sewage sludge Global warming potential (GWP_{100}): 28 CO_2e / CH_4	**19’081**	**t CO_2e / a**

Without the use of the pyrolysis plants at ÖKT, the corresponding heat output for drying of 850 kW would have had to be provided by burning liquid gas. It should be mentioned here that the use of a biomass combustion plant was not an option, since no further added value could be achieved anymore. As explained in this paper, pyrolysis on the other hand is characterized using local synergies with biogas plants and agriculture. Pyrolysis contributes to the environmental goals of climate protection and circular economy.

If the value from the IPCC report is used for the emission factor for the combustion of liquid gas, a greenhouse gas emission of **1’584 t CO2e per year** is calculated. A correspondingly high greenhouse gas reduction is therefore achieved by replacing the liquefied gas with climate-neutral energy from the pyrolysis plant. The underlying assumptions for the calculation are listed in the appendix.

Table 2: GHG emissions from the provision of heat by LPG

Heat output of the pyrolysis plants	850	kW
Annual heat provided through pyrolysis = Annual fossil heat saved	26’806	GJ / a
GHG emissions in the provision of heat demand by LPG [1].	**1’584**	**t CO_2e / a**

Furthermore, drying reduces the weight of the sewage sludge, which in turn reduces emissions from sewage sludge transportation. For the following calculation example, 50 km is assumed (emissions from truck transport: emissions data from the German Federal Environment Agency [4]). Together with the input values of ÖKT, this results in an emission reduction of **75 t CO_2e per year**. Although this reduction is negligible, the alternative with the lower transport emissions should be preferred.

Table 3: Savings in GHG emissions during sewage sludge transport through drying

Amount of non-dewatered sewage sludge produced	18’000	t / a
Transport emissions of sewage sludge	106	tCO_2e / a
Dried sewage sludge produced by ÖKT plant	5’200	T / a
Transport emissions of dried sewage sludge	31	tCO_2e / a
Saved transport emissions	**75**	**t CO_2e / a**

According to EBC guidelines, 70 % of the pyrolysis gas must be used for material or energy purposes. With the waste heat utilization of the recycled gases this requirement is ensured.

4. Carbon sink of biochar

When the biochar is applied to a terrestrial system, a long-term carbon sink is created. In the greenhouse gas balancing of the synergy between sewage sludge drying and pyrolysis, the consideration of this carbon sink is essential.
The quantification of this product is done by the EBC carbon sink certification: as described in the guidelines, this takes the carbon content of the produced biochar and subtracts the emissions from biomass preparation and processing, transport and the pyrolysis process. The latter includes, among other things, the use of electricity to operate the plant, as well as the possible use of fossil fuels to preheat the combustion chambers. Emissions from the construction and maintenance of the pyrolysis plant are covered by a safety margin.

It is known that methane leakage occurs in the CHP unit of the ÖKT plant. This is due to the fact that the produced biogas is not completely burned in the power plant – in case of complete combustion, higher NOx emissions would appear, which would exceed the legal limits for air pollution control. Due to this, methane emissions are suspected in the exhaust air of the sewage sludge dryer, which is heated by the waste heat of the CHP.

An important aspect of carbon sink certification is the quantification of methane emissions from the pyrolysis plant: The methane-containing pyrolysis gas is captured according to the EBC guideline and subsequently incinerated, which means that relatively low methane levels can be expected in the plant's flue gas. However, due to the high greenhouse gas potential of methane over a 20-year period (86 times greater than that of CO_2), CO_2e emissions are calculated to have a impact on the carbon footprint of the biochar. Within the scope of the carbon sink certification, CH_4 determination is required: This can be done by individual measurements at the plant. However, since individual measurements of methane are costly, EBC type certification is offered, in which the plant type of a manufacturer is certified: Here, three identical plants must be in operation, and methane measurements must be available for two of these plants. The average methane emission of these plants can thus be transferred across the board for all plants of the certified plant type.

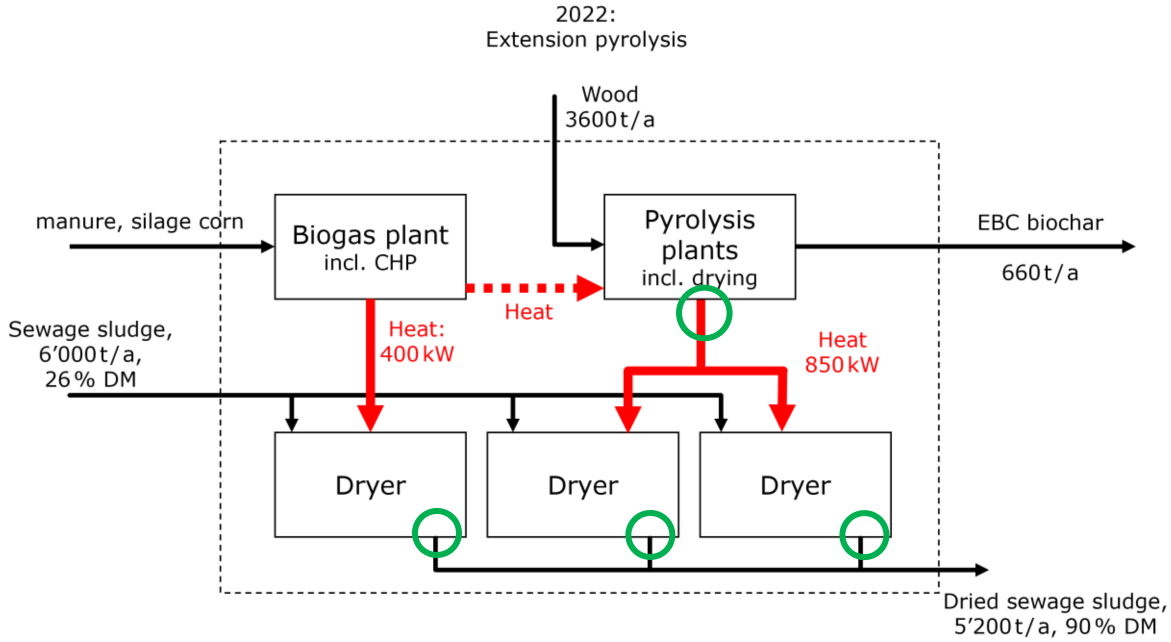

Figure 7: Flowchart of the entire plant in 2022: To quantify the methane emissions and the avoidance of methane leakage, measurements are planned for the Offenhausen plant at the points marked in green.

For the certification, methane measurements were carried out on the exhaust gas after the pyrolysis plant. It is assumed that these emissions can be completely compensated by avoiding the methane leakage. To be able to quantify this avoidance, further CH_4 measurements on the exhaust gases downstream of the three sewage sludge dryers are planned for the Offenhausen plant. The EBC carbon sink certification of a biochar batch at another identical NGE plant will allow the type certification of the manufacturer to be completed.

The carbon balance of the biochar till factory gate is referred to as the **carbon sink potential**. The carbon sink potential at the Offenhausen plant was determined as following during certification:

- Emissions from biomass cultivation are not taken into account, since the feedstock is wood chips from waste wood, and are thus considered climate-neutral. In the context of the carbon sink certification, the emissions from the transport of the biomass have been determined as 4.61 t CO_2e / a, those from the preparation of the biomass for pyrolysis as 218.66 t CO_2e / a.

- The drying of the feedstock, the electricity consumption of the pyrolysis plant, and the preheating of the pyrolysis do not cause any GHG emissions since climate-neutral energy from the biogas plant and waste heat from the CHP plant are used for these processes.

- Based on the methane measurements at the pyrolysis plant, an annual emission of 0.36 t CH_4 was determined. It can be assumed that these low emissions can be compensated by avoiding the methane leakage.

The determination of the carbon sink also includes a safety margin, which is 10 % of all emissions along the life cycle. This margin covers all indirect emissions from the biochar production process that were not quantified in the carbon sink calculation. These processes include, among others, the construction and maintenance of the pyrolysis plant.
The calculated carbon sink potential amounts to 1’936.83 t CO_2e per year. For the final carbon sink, the transport and processing emissions from the factory gate (pyrolysis plant) to the actual incorporation of the biochar into a matrix (soil, compost, concrete, etc.) would have to be subtracted. Regarding this biochar project, it is recommended to apply the biochar at the nearby farm. In this way, transport costs can be minimized, and the benefits of the biochar can be used at the local level – thus coming closer to the environmental goal of a circular economy. Accordingly, transport emissions can be assumed to be negligible.

Table 4: Carbon sink potential and carbon sink of the biochar.
(Values taken from the carbon sink potential certificate, rounding differences should be noted).

Annual biochar production	660	t TS / a	data ÖKT
Carbon content	92 %		data ÖKT
Carbon storage of the annual production	-2’216.72	t CO_2e / a	
Emissions biomass cultivation	0	t CO_2e / a	neglected, because climate-neutral waste wood
Emissions transport biomass	4.61	t CO_2e / a	
Emissions preparation biomass	218.88	t CO_2e / a	
Emissions drying biomass	0	t CO_2e / a	climate-neutral heat from biogas plant
Emissions electricity consumption pyrolysis	0	t CO_2e / a	climate-neutral electricity from biogas plant
Emissions preheating pyrolysis	0	t CO_2e / a	climate-neutral heat from biogas plant
Methane emissions pyrolysis plant	30.96	t CO_2e / a	GWP20 factor: 86 t CO_2e / t CH_4
Safety margin	25.44	t CO_2e / a	
Carbon sink potential	**-1’936.83**	**t CO_2e / a**	
Emissions transport biochar	0	t CO_2e / a	neglected here
Carbon sink	**-1’936.83**	**t CO_2e / a**	

5. GHG Savings: Balance Sheet and Conclusion

Since its expansion in 2020, the drying plant 'Ökologische Klärschlammtrocknung Offenhausen' dries 18'000 t of sewage sludge per year. Initially, the ÖKT used a biogas reactor and a liquid gas burner to provide the heat for drying. To make the operation more climate-friendly, the liquid gas burner was replaced by two pyrolysis plants in 2022. Emissions from fossil fuel were saved by using the heat from the pyrolysis plant; furthermore, the pyrolysis process produces high-quality biochar. By applying this biochar to the terrestrial system, a long-term carbon sink is created. To visualize the CO_2 saving potential of the whole project, three alternative scenarios for sewage sludge treatment are compared:

- No sewage sludge drying: Without drying by ÖKT, the annual accumulation of sewage sludge would be spread on agricultural fields. This would result in methane emissions through of ca. **19'081 t CO2e / a**.

- Sewage sludge drying with fossil heat: Until the conversion in 2022, a heat output of 400 kW was provided by the biogas plant and 850 kW by the liquid gas burner for drying the sewage sludge. The use of liquid gas as a fossil energy source was associated with greenhouse gas emissions of an estimated **1'584 t CO2e / a**.

- The synergy between sewage sludge drying and biochar production, as well as the subsequent application of the biochar, creates a carbon sink of about **1'937 t CO2e / a**.

The comparison between the scenarios is shown graphically in the following diagram:

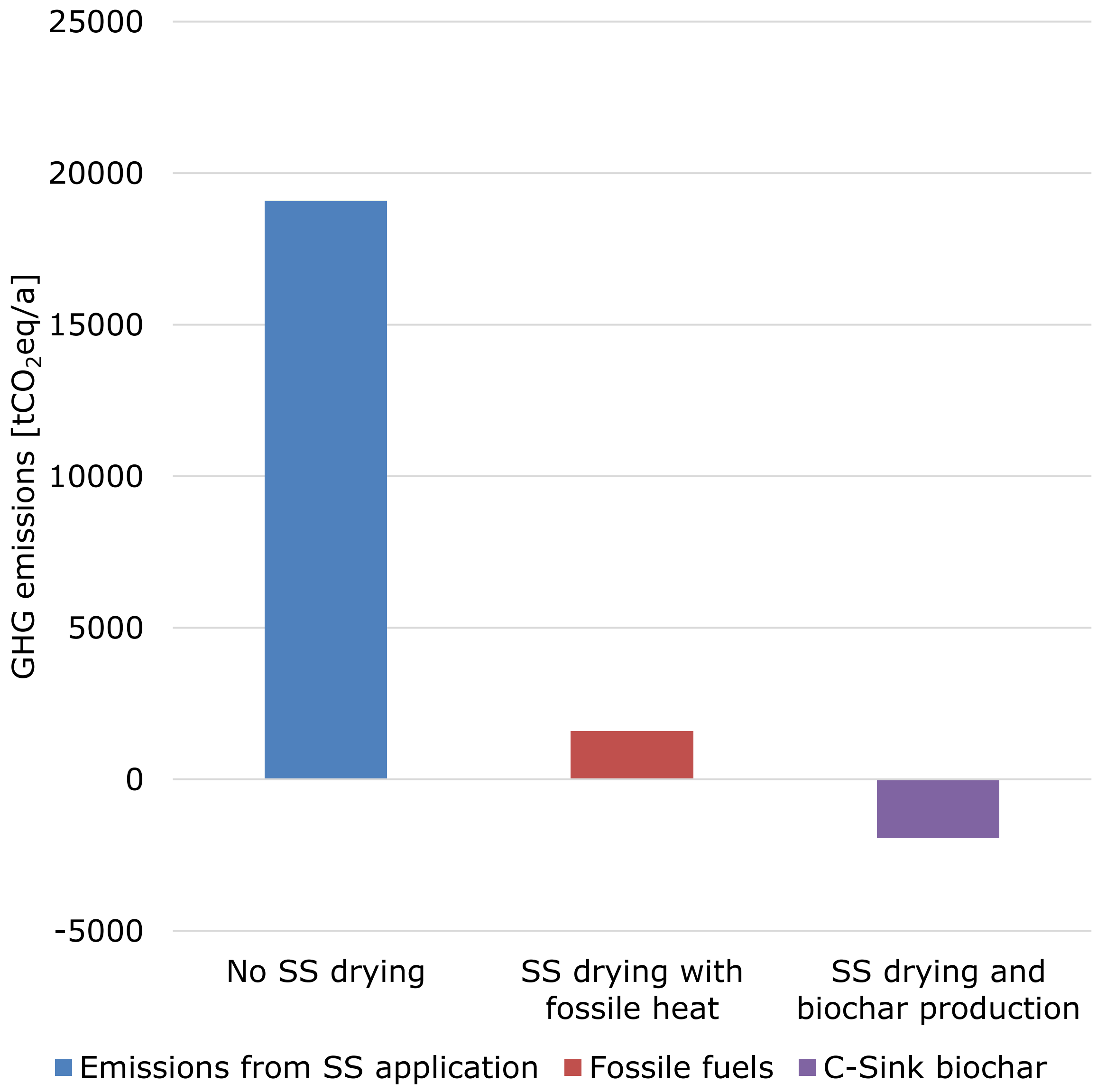

Figure 8: The greenhouse gas reduction from the pyrolysis project is shown by comparing three alternative scenarios for sewage sludge treatment.

When comparing these three scenarios, it is visible that the significant improvement in the climate balance is achieved by avoiding the land application of sewage sludge. However, it must be considered that the spreading of sewage sludge will no longer be legally permitted in Germany and Austria by the end of the decade anyway.

Considering the two alternatives to sewage sludge drying presented here, the synergy between biochar production and sewage sludge treatment stands out as a climate-friendly and even climate-positive alternative due to the creation of the carbon sink.

Within the framework of EU taxonomy, a pyrolysis project with local synergies can make a significant contribution regarding the aspect 'climate change mitigation'. The use of biochar as a fertilizer additive in local agriculture also meets the environmental objective of 'transition to a circular economy'.

The calculated CO_2 savings are particularly interesting for pyrolysis plants which – similar to the ÖKT – are connected to wastewater treatment plants, biowaste recycling plants and / or agricultural operations: For cities and municipalities that have set themselves climate targets, greenhouse gas-reducing process optimizations in the municipal infrastructure are indispensable. The pyrolysis projects at biogas and wastewater treatment plants can contribute to the achievement of the set climate targets. In case of synergies of the pyrolysis plant with agricultural enterprises, the described CO_2 savings can be credited in the climate balance of the agricultural products. Sites with similar process optimizations have the potential to be classified as sustainable by the EU Taxonomy Regulation. This positively distinguishes a company from its competitors, which in turn creates an incentive for investors.

In follow-up studies, synergies between pyrolysis and steel, plastics or construction industries can be addressed.

6. Further aspects

a.) Additional benefits of using the biochar in agricultural fields

Even after the application of the biochar in agricultural soils, further additional benefits in terms of climate impact can be observed: The biochar promotes the build-up of humus, thus counteracting the frequently observed degradation of organic carbon. [6]
In addition, biochar is valued for its water retention potential. Triggered by climate change, increased droughts as well as heavy rains are expected in the coming years. Due to the capacity of biochar to store water, extreme weather events can be balanced. The biochar thus contributes to climate change adaptation – one of the environmental goals of the EU taxonomy.

b.) Use of the biochar in the biogas reactor

In research, the use of biochar in biogas plants is assumed to have further additional benefits [2] With regard to the project in Offenhausen, synergies with the biogas reactor could thus be offered:

- By adding biochar to the biogas reactor, the alkalinity in the reactor can be increased, which in turn is beneficial for fermentation.
- Nutrients such as nitrogen or sulphur can be absorbed by the biochar. These substances would otherwise be found in the biogas as N_2O or H_2S emissions. By adding biochar, a purer biogas with higher methane content can be produced.
- For hydrolysis, the first and crucial sub-process of fermentation, a high residence time of the microorganisms is required. The porous structure of the biochar provides a larger surface area for the microorganisms, on which the organisms can form biofilms and thus initiate fermentation.

However, these effects are still the subject of research and have hardly been tested on an industrial scale. Further knowledge from research and development is needed so that the synergy between plant carbon production and anaerobic digestion can find its way into regulations. The points mentioned do not necessarily contribute to an improved climate balance, but still represent investment incentives for a pyrolysis project.

c.) Further synergies: Pyrolysis of sewage sludge

Another interesting synergy in the field of sewage sludge treatment is the pyrolysis of sewage sludge: The obligation to recover phosphorus leads to further technical challenges (mono-incineration systems), where pyrolysis technology can again play an interesting role. The sewage treatment plant Niederfrohna (Saxony) is an example for this, where drying and pyrolysis take place on a sewage treatment plant, and the further use of the produced coal product (sewage sludge carbonisate), accompanied by university, is under investigation [5] Beside Niederfrohna a PyroDry system was installed in Q2 2023 in Nordhausen (GER) also for processing sewage sludge on a waste water treatment plant for research work. [7]

Appendix

Assumptions Calculation:

CO_2e footprint liquefied petroleum gas 59.1 g CO_2e / MJ Source: [1]

CO_2e footprint truck transport 118 g CO_2e / tkm Source: [4]

Calculation method CH_4 outgassing when sewage sludge is discharged: Source: [3]

Tabelle 2.19: Bildung von Methan bei der Deponierung von Klärschlamm

Abfall im Sinne § 3 (7) AWG Stoffbezeichnung gemäß ÖNORM S 2100	Menge – 25 % TS (t/a)	Menge – 34 % TS (t/a) [1]	Methangas-bildungs-rate (m^3/t*a) [2]	Methangas-bildung gesamt (m^3/a)	Methangas-bildung gesamt (t/a) [3]	CO_2 Äquivalente (t/a) [4]
SN 945: Stabilisierte Schlämme aus mechanisch-biologischer Abwasserbehandlung; SN 948: Schlämme aus der Abwasserbehandlung	600.000	441.176	69,05	30.463.202	21.842	388.619
	800.000	588.235	69,05	40.617.626	29.123	531.495
	382.000	280.882	69,05	19.394.870	13.906	253.790

[1] Als Basis für die Berechnungen dient in der Studie von Baumeler eine Trockensubstanz von 34 %. Daher wurden die entsprechenden Werte aus der Tabelle 2.18 ebenfalls auf 34 % umgerechnet.

[2] Für die SN 945 wird ein Wert von 52,2 m^3/t*a bei einem jährlichen Anfall von 240.000 t, für die SN 948 werden 87,3 m^3/t*a bei einem Anfall von 225.000 t/a angegeben; der in der Tabelle angeführte Wert stellt einen Mittelwert dar.

[3] Dichte Methan: 0,717 kg/m^3

[4] Äquivalenzfaktor: 21; von den Werten wurde bereits die Menge CO_2 abgezogen, welche aus der organischen Substanz durch Verbrennung freigesetzt worden wäre, statt zur Methanbildung beizutragen.

Figure 9: Calculation method CH_4 outgassing when sewage sludge is discharged (in German) Source: [3]

Sources

[1] IPCC, 2018: 'Properties of CO2 and carbon-based fuels' (link)

[2] Masebinu, S. O., Fanoro, O. T., Insam, H., Mbohwa, C., Wagner, A. O., Markt, R., & Hupfauf, S. (2022). 'Can the addition of biochar improve the performance of biogas digesters operated at 45 C?'. Environmental Engineering Research, 27(2). (link)

[3] Umweltbundesamt (A), 2001: 'Mitverbrennung von Klärschlamm in kalorischen Kraftwerken' (link)

[4] Umweltbundesamt (D), 2021: Emissionsdaten (link)

[5] Zweckverband Frohnbach – 'Der Verband und seine Strukturen – Zweckverband Frohnbach' (link)

[6] Blanco-Canqui, H., Laird, D. A., Heaton, E. A., Rathke, S., & Acharya, B. S. (2020). 'Soil carbon increased by twice the amount of biochar carbon applied after 6 years: Field evidence of negative priming'. GCB Bioenergy, 12(4), 240-251. (link)

[7] 'Regionale Kreislaufwirtschaft zur lokalen Wiederverwendung von Klärschlamm und Biomasse mit der Option der CO2 Bilanzierung (CarboMass) ', Hochschule Nordhausen; CarboMass (hs-nordhausen.de)

[8] EU Taxonomy Regulation (link)

EBC (2012-2023) 'European Biochar Certificate – Guidelines for a Sustainable Production of Biochar. ' Carbon Standards International (CSI), Frick, Switzerland. (http://european-biochar.org). Version 10.3 from 5th Apr 2022 (link)

EBC (2020), 'Certification of the carbon sink potential of biochar', Ithaka Institute, Arbaz, Switzerland. (http://european-biochar.org). Version 2.1E of 1st February 2021 (link)