Circular bioeconomy strategy for the federal state capital Stuttgart (ZirBioS)

Version 1.3 (July 2024)

STUTTGART

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With the co-operation of:
LHS Municipal Landscaping, Cemetery and Forestry Authority
Stuttgart Urban Wastewater Management (SES; in-house operation)
Human Resources Department LHS
Stuttgart Waste Management (AWS; in-house operation)
Building Department LHS
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Office for Urban Planning and Housing LHS

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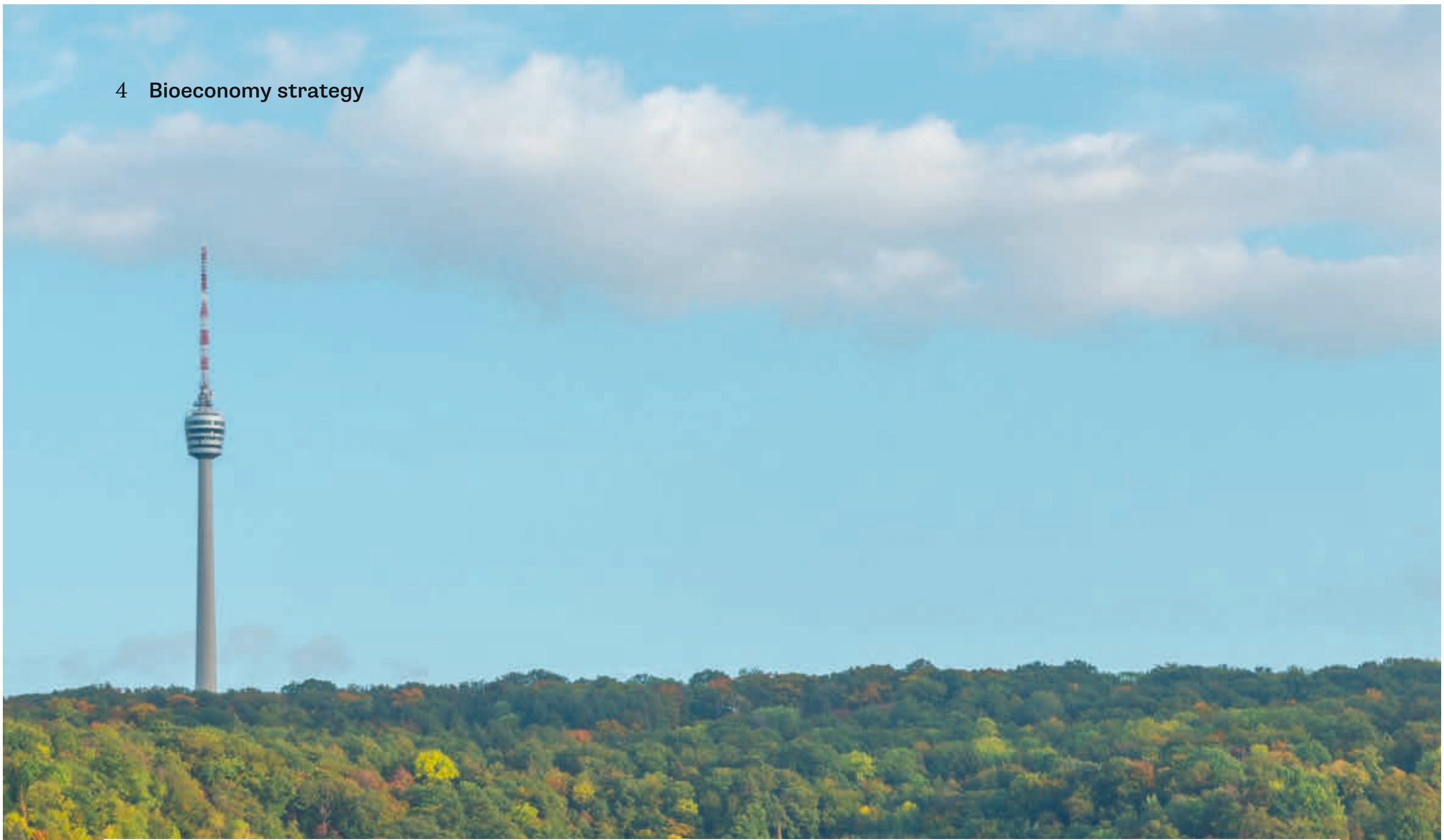


GLOSSARY

CCU
Carbon Capture and Utilisation refers to the capture, transport and subsequent use of carbon compounds. The carbon is thus fed into at least one further utilisation cycle and is stored within the product's service life. CCU only counts as a C-sink if the carbon is fixed in a product or application over a long period of time (see Permanence).

CDR
Carbon Dioxide Removal refers to technologies aiming to remove carbon dioxide from the Earth's atmosphere and long-term storage. This reduces the CO_2 content of the atmosphere and combats the climate crisis. In contrast to carbon capture and storage (CCS) technologies, which aim to capture CO_2 emissions at source, CDR technologies aim to remove CO_2 already present in the atmosphere.

CARBON SINKS
Carbon sinks play a significant role in the global carbon cycle and in the fight against the climate crisis. Natural carbon sinks are oceans, forests or permafrost soils that have absorbed more carbon than they have released over a long period of time. These natural C sinks are threatened by the climate crisis and have already become a C source in some areas. The permanence of a C-sink is decisive (see Permanence).

CERTIFIED BIOCHAR
Certification (e.g. EBC certificate) can ensure the sustainable production of biochar. This enables biochar producers to prove and guarantee the quality of the biochar (PAH, PCB, PCDD/F) to users and authorities (EBC 2023).

EMISSIONS GAP
Emissions gap, documentation of the gap between agreed climate targets and actual climate policy. If all the pledges currently being made by the international community (NDCs) are added together, global warming of 2.5-2.9°C will be reached by the end of this century (UNEP, Emissions Gap Report 2023).

GHG
Greenhouse gases

LHS
This is the abbreviation for *Landeshauptstadt* Stuttgart. In this paper it generally refers to the City of Stuttgart and not the city suburbs of the federal state capital of Baden-Württemberg. This English rendering of the German original uses the following interchangeably to mean Landeshauptstadt Stuttgart: City of Stuttgart, Stuttgart city, centre of Stuttgart, Stuttgart.

PERMANENCE
Permanence describes the longevity of a carbon sink, i.e. how long the carbon atom is bound or sequestered. Furthermore, this term is also used in connection with the length of time a CO_2 molecule remains in the atmosphere. Some of the CO_2 that is emitted today will still be present as an effective greenhouse gas in several hundred years' time due to its slow degradation in the atmosphere.

Preliminary remarks

Stuttgart intends to become climate-neutral by 2035. This was decided by the municipal council in July 2022 at the proposal of the mayor, and we are working consistently to attain this. Consequently, we follow many proven principles such as the efficient use of energy and energy saving. And, of course, it is also about replacing fossil fuels with renewable energy.
To achieve this transformation, we also need to look at material flows. Over 14 million tonnes of materials and goods flow into the City of Stuttgart every year. The circular economy and bio-economy help to make these material flows as sustainable as possible. In short, the bioeconomy describes an economic system that utilises biological resources, processes and principles in order to offer products and services. This strategy focuses, in particular, on the biomass flows in Stuttgart.

The aim of the bioeconomy is, firstly, to replace fossil materials with biological materials as far as possible. Secondly, it aims to utilise biogenic material flows as effectively as possible. Every day, the City of Stuttgart, its departments and municipal utilities process large quantities of biological materials, from green waste to organic waste and sludge. Even if these substances do not play a major role in most people's everyday lives, they still harbour enormous potential.

With Stuttgart’s circular bioeconomy strategy, we are demonstrating the future fields and potential offered by a sustainable and cycle-orientated bioeconomy in the federal state capital of Baden-Württemberg. To this end, we are presenting 22 specific measures that can be implemented over the coming years. These include, for the first time, measures to store carbon permanently in the soil, on green roofs or in cement and concrete, which, in turn, create urgently needed carbon sinks. In addition, we wish to avoid unnecessary waste and reduce greenhouse gases by implementing the specific measures.

I would like to convey special thanks to the colleagues from the municipal offices and in-house operations which filled this potential analysis with content. I also wish to thank the Baden-Württemberg Ministry for the Environment, Climate Protection and the Energy Sector, whose funding made the preparation of this strategy possible.

Martin Körner

Martin Körner

Head of Policy Department for Climate Protection, Mobility and Housing, Landeshauptstadt Stuttgart

Bioeconomy

The Landeshauptstadt Stuttgart (LHS) defines bioeconomy in line with the Baden-Württemberg government's definition as an economic system that uses the knowledge-based production and utilisation of biological resources, processes and principles to provide products and services in all economic sectors as part of a sustainable economic and social system (Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg 2019). The bioeconomy is more than just a substitution strategy for fossil raw materials (e.g. packaging materials made from cellulose instead of petroleum-based plastic). Indeed, "a sustainable bioeconomy aims to intelligently manage natural resources and regional material flows to provide food and feed as well as materials and raw materials for material and energy use" (Baden-Württemberg Ministry of the Environment, Climate Protection and the Energy Sector 2019).

"Intelligent management of natural resources and regional material flows"

For example, scarce resources such as phosphorus and nitrogen can be extracted from sludge instead of dumping these raw materials in mines, as has been the practice for decades. Certified biochar can be produced from municipal green waste, in which the carbon is stored for several centuries. Not only does this type of carbon sink make sense from a bioeconomic perspective. As regards the climate, certified biochar offers a technology that is ready for use today to generate negative emissions.

One focus is also on closing cycles through innovative biological and chemical processes. For example, residual materials from the food industry, waste of biogenic origin or waste water are utilised as a resource for new products. An increasingly popular example is carbon capture in incineration plants (e.g. waste incineration, sludge incineration, wood incineration). This can make a significant contribution to negative emissions in the future. After all, what is not emitted in the form of greenhouse gases today does not have to be extracted from the atmosphere in an energy-intensive process the day after tomorrow (Kotz et al. 2024).

As products ought to be used for as long as possible in the circular economy (European Union 2023), incineration is always the last resort. In Germany, this objective is contained in the waste hierarchy (prevention, reuse, recycling, energy recovery, disposal) in the Recycling Management Act. With regard to biomass, the Federal Environment Agency came to this conclusion back in 2014: "In the case of a cascade utilisation of the raw material (first materially - as often as possible - and finally energetically), material utilisation is far superior to energetic utilisation." (Carus et al. 2014). This strategy largely follows the principle of prioritising material use over energy use.

The closing of cycles and utilisation cascades (material use before energy use), the bioeconomy helps to reduce GHGs, conserve natural resources and strengthen biodiversity. Bioeconomic approaches enable a climate-neutral economic foundation. This is essential for achieving climate neutrality in Stuttgart by 2035 and also helps to secure prosperity, economic power and innovative and sustainable jobs in the region.

"What is not emitted in the form of greenhouse gases today does not have to be extracted from the atmosphere in an energy-intensive process the day after tomorrow."

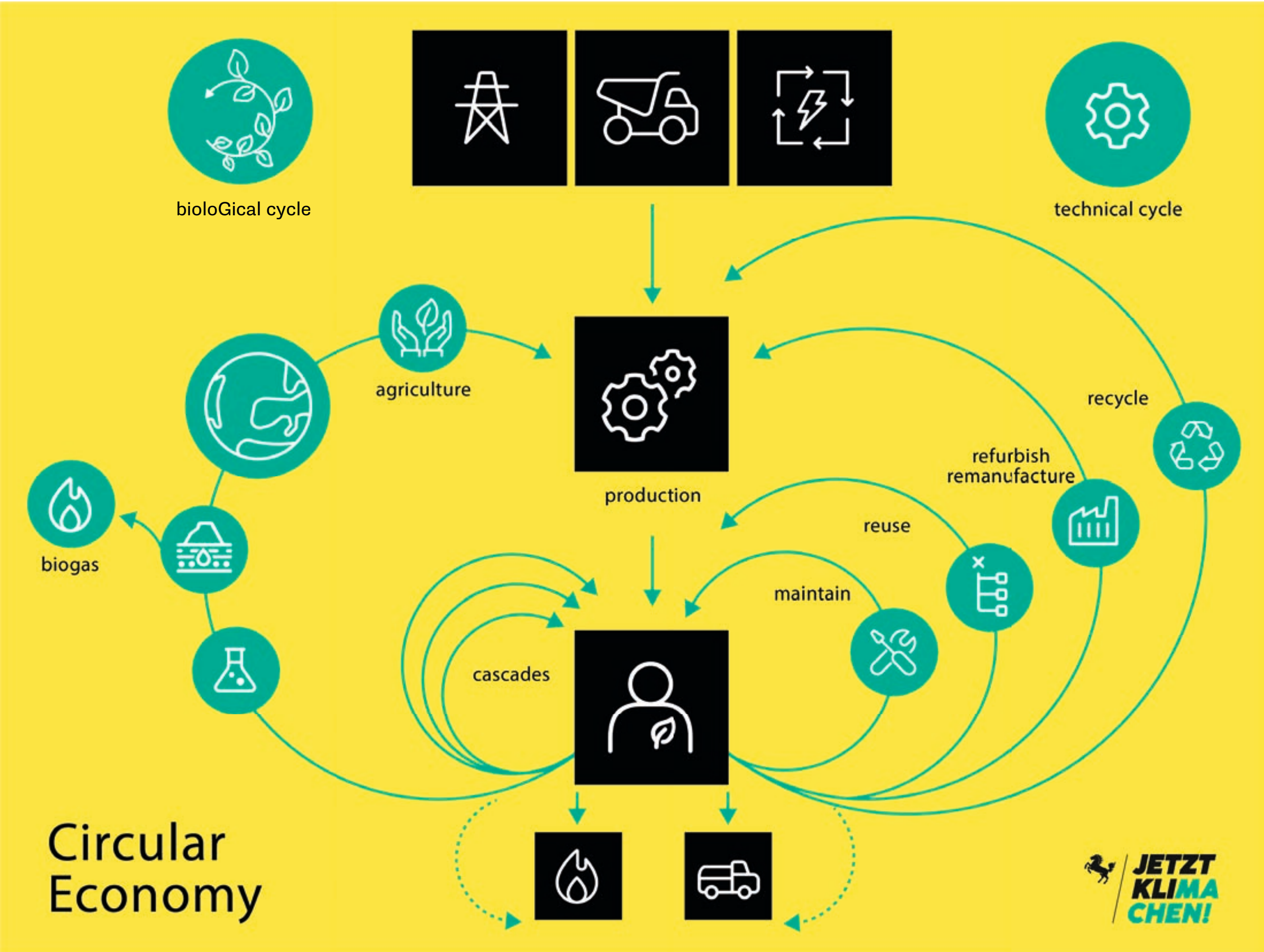


Fig. 1: Bioeconomy as an essential part of the circular economy. The left-hand side of the butterfly diagram deals with the biological cycle – the bioeconomy, while the right-hand side of the diagram shows the technological cycle of the circular economy.

Goals and vision of the LHS circular bioeconomy strategy

STATUS QUO AND DEVELOPMENT

The City of Stuttgart is the centre of the European metropolitan region of Stuttgart, which is home to around 5.3 million people. Stuttgart is one of the largest conurbations in Germany with around 2.8 million inhabitants in the region and over 600,000 people in the city. Of the approximately 524,000 people employed in Stuttgart, 19% work in manufacturing and 80% are in the service sector.

In July 2022, the municipal council adopted the goal of making Stuttgart climate-neutral by 2035. This decision was predominantly based on the "Net-Zero Stuttgart" study, which depicts the federal state capital's climate roadmap (Landeshauptstadt Stuttgart 2022). The climate roadmap contains 17 packages of measures that the city must implement to achieve climate neutrality.

The resource turnaround is addressed in the 16th package of measures "Reduction of grey energy through a circular economy strategy". The planning and implementation of the measure is coordinated by a Circular Economy Coordinator, who is based in the Climate Action Office. Besides traditional waste management, the holistic strategic approach includes technical cycles on the one hand and biological cycles on the other. An urban, circular bioeconomy strategy (ZirBioS) pursued by LHS is therefore an integral part of a holistic circular economy strategy of Stuttgart. The bioeconomy strategy creates a basis that can be continuously expanded to include other aspects of the bioeconomy, including those beyond the circular economy.

The project is funded by the Baden-Württemberg Ministry for the Environment, Climate Protection and the Energy Sector from 01.02.2023 to 31.08.2024.

GOALS AND VISION OF THE BIOECONOMY STRATEGY

This strategy sets the course for the coordinated implementation of the bioeconomy in Stuttgart for the first time. The strategy is aimed at achieving the following results:

- List of existing players and activities in the bioeconomy in LHS
- Mapping biogenic (residual) materials in LHS
- Identification and quantification of the type of (residual) substances in LHS
- Potential analysis for unutilised or underutilised biogenic material flows
- Examination of the possibility of creating urban carbon sinks from biogenic (residual) materials
- Implementation of direct measures
- Realisation of pilots (little tested processes and technologies)

A large number of local government offices and inhouse operations were involved in the development of the Stuttgart bioeconomy strategy. Moreover, we worked closely with local stakeholders to develop practical measures that can be implemented.

The following vision formed the core of the project:
Biogenic waste materials are utilised in a cascading manner throughout the city in accordance with the Recycling Management Act. The focus here is on material utilisation before energy-related utilisation is introduced as the final stage in the product's life cycle. In addition, the course is already being set today to greatly scale negative emissions (CDR; Carbon Dioxide Removal). Despite ambitious measures to reduce emissions, it is already clear today that enormous quantities of CO_2 must be removed from the atmosphere worldwide in the long term in order to achieve net zero targets and remain below the global 2 °C temperature limit in the long term. The bioeconomy, with its multifaceted approaches, offers concrete potential for optimisation and use.

Negative emissions & carbon sinks

There is a scientific consensus that several hundred billion tonnes of CO_2 must be removed from the atmosphere over the course of this century (negative emissions, CDR; carbon dioxide removal) in order to limit the global temperature rise to below 2 °C (Smith et. al 2023 & IPCC 2021). Although GHG reduction measures reduce the annual contribution of CO_2, the total amount of CO_2 responsible for the greenhouse effect initially remains the same or continues to rise due to the slow molecular degradation of CO_2 in the atmosphere. Achieving net zero does not stop the greenhouse effect, it simply does not increase it.

Initial scenarios for Germany show that it will be necessary to remove at least 36-130 million tonnes of CO_2 from the atmosphere every year from 2045 through various CDR measures (Fuss et al. 2021). The actual requirement is very likely to be many times higher due to the "emissions gap" (United Nations Environmental Programme 2023). In particular, the removal of historical emissions (e.g. from the first half of this century) will also have to be taken into account in the long term in addition to the removal of acutely unavoidable residual emissions (IPCC 2022, Erlach et al. 2022). Stuttgart's residual emissions are expected to amount to 0.2 million tonnes of CO_2 / year by 2035 (City of Stuttgart 2022). This corresponds to 6% of Stuttgart's total emissions from 2019. The 0.2 million tonnes of CO_2 do not yet include emissions that could potentially arise if Stuttgart does not succeed in meeting the targeted CO_2 reduction path (see Figure 2).

To achieve the targets in the Paris Agreement, it is essential to avoid emissions, reduce emissions and, ultimately, offset unavoidable emissions. This applies, in particular, to emissions that are generated across sectors through energy consumption and are already recorded as part of the urban territorial balance. However, if we take a closer look at grey energy, which is difficult to offset, consistent avoidance and reduction of emissions are very likely insufficient to achieve the target (Smith et al 2023). Grey energy describes energy used to manufacture, transport, store, sell and dispose of a product. This means that every product imported into the City of Stuttgart causes greenhouse gas emissions that are not included in the urban territorial balance.

Offsetting greenhouse gases must never be seen as an alternative to avoiding and reducing emissions. Rather, offsetting GHGs should be seen as a necessary parallel technology that primarily serves to compensate for unavoidable emissions and also to bind historical emissions from the first half of this century. An extremely fast, bold and, above all, unbureaucratic scaling of versatile CDR technologies (portfolio approach) is the only opportunity of not only achieving net zero but also reversing the climate crisis in the long term (Merfort et al. 2023).

"A portfolio approach to CDR technologies is the only way to reverse the climate crisis."

To determine possible topics for urban carbon sinks and to identify potential, the creation of a carbon sink portfolio for Stuttgart was commissioned for this bioeconomy strategy (see appendix: Carbon sink portfolio). This study is intended to provide an initial overview of possibilities for local carbon sinks, which would be followed by deriving concrete measures to establish urban C sinks and incorporating a process for the integration of negative emissions into the monitoring of net zero target achievement.

SCENARIO A)

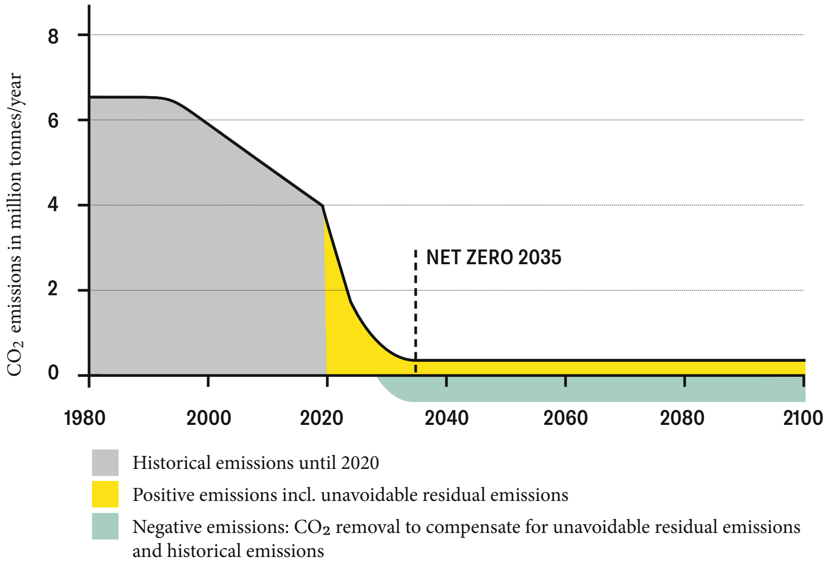


Fig. 2: Scenario a) By immediately and radically capping CO_2 emissions, net zero is achieved in Stuttgart in 2035. Unavoidable residual emissions are offset by negative emissions in order to maintain net zero in the long term.

SCENARIO B)

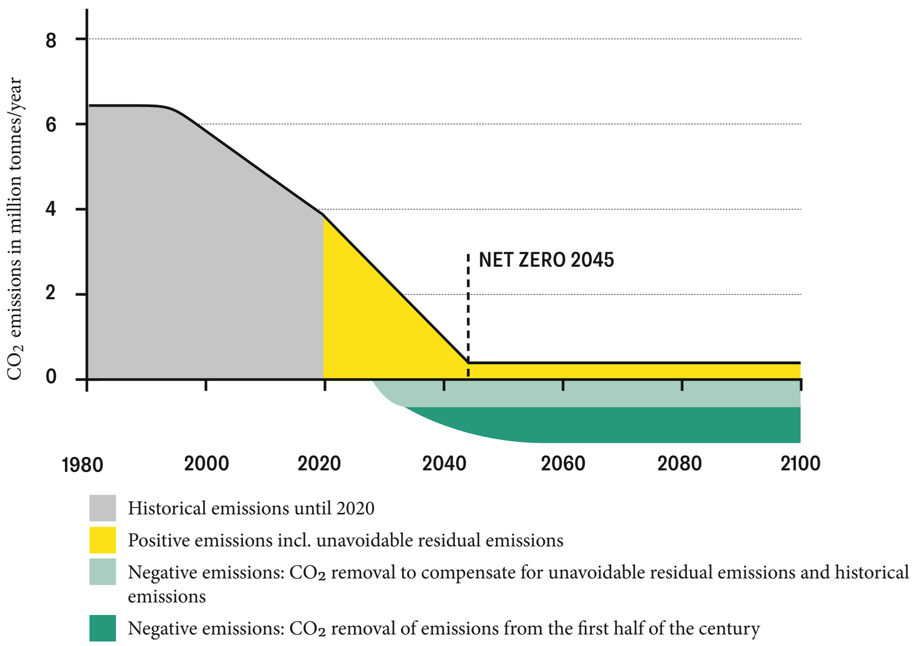


Fig. 2.1: Scenario b) CO_2 emissions are reduced more slowly. Nevertheless, a much larger CO_2 removal will be necessary in the second half of the century in order to achieve net zero in the long term. Graphic based on Erlach et al. (2022).

Project work/results

IDENTIFICATION OF BIOECONOMY STAKEHOLDERS IN LHS

4.1.1 METHODOLOGICAL APPROACH

During the initial stage, relevant stakeholders (municipal offices and in-house companies, research institutions, SMEs, start-ups and other multipliers) were identified using the following data sources: the bioregio-stern.de website, the federal funding catalogue, the Orbis company database, the Bioeconomy Lab project and the report "Bioökonomie-Region Stuttgart – Potenziale der Bioökonomie im urbanen, industriellen Raum". Particular attention was paid to the fact that the organisations currently have at least one branch in the centre of Stuttgart and that they have the potential to contribute to the recycling of biogenic raw and residual materials as suppliers, consumers or technology providers. The main focus was placed on LHS municipal offices and in-house operations, as this is where the city can utilise its direct sphere of influence.

The food industry and catering trade as bioeconomic players in the city were excluded from this study, as there is little concrete data specific to LHS and it was not possible to derive measures for LHS within the framework of ZirBioS.

4.1.2 RESULT

Within the city limits, a total of 150 stakeholders were identified as a bioeconomic core group with the potential to participate in the utilisation of biogenic raw/residual materials as suppliers, consumers or technology providers. One example of this is a landscape maintenance company that delivers green waste from private households in LHS to the municipal collection centres of the LHS Municipal Landscaping, Cemetery and Forestry Authority, but is also a customer for locally produced substrates (e.g. compost or certified biochar) from the delivered and processed raw material.

There is a particularly large number of players in the areas of landscape conservation, manufacturing, waste disposal and recycling as well as agriculture and forestry.

"A main focus was placed on LHS municipal offices and in-house operations."

Bioeconomy stakeholder, state capital Stuttgart

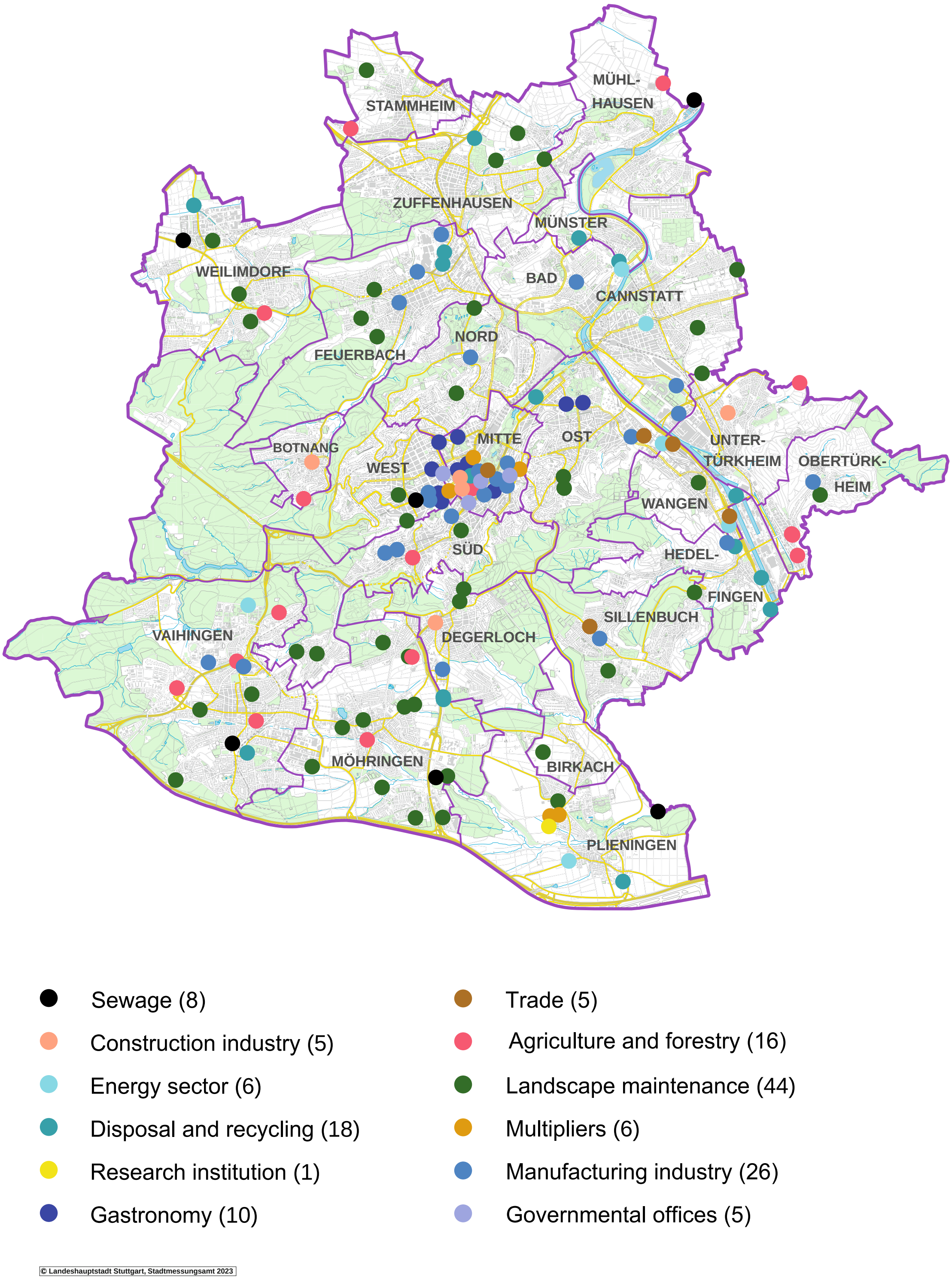


Fig. 3: 150 bioeconomy stakeholders in LHS, focussing on municipal offices and in-house operations, but excluding private catering and food retail.

Material flow analysis

4.2.1 METHODOLOGICAL APPROACH

Some of the most important biogenic material flows are within the direct sphere of influence of the city administration, primarily the green waste produced (LHS Municipal Landscaping, Cemetery and Forestry Authority), organic waste (Stuttgart Waste Management) and sludge (Stuttgart Urban Wastewater Management). Within the limited project framework of ZirBioS, a focus was placed on these material flows. The diagrams primarily contain these flows, but refer to additional important material flows within LHS and beyond the city limits.

The majority of the data presented here refers to tonnages collected internally by LHS from 2022, the year of the survey, unless otherwise stated. As regards the material flow of municipal green waste, it should be noted that these are estimated tonnage figures, as there is no infrastructure for precise measurement. The proportion of biogenic materials in the residual waste bin relates to an AWS survey in 2017. The material flow of food waste is taken from the Food Waste in Germany - Baseline 2015 Report (see Schmidt et al. 2019).

4.2.2 RESULT

To minimise the complexity, the large number of material flows is shown in two diagrams. The first material flow diagram shows the flows of the LHS drainage system. A second, separate diagram shows the material flows managed by Stuttgart Urban Wastewater Management and the LHS Municipal Landscaping, Cemetery and Forestry Authority. All material flows with further utilisation potential were highlighted in red on the material flow diagrams. There is considerable bioeconomic utilisation potential for the following material flows:

- Reduction of emissions (e.g. nitrous oxide, methane, CO_2) in aeration tanks, sludge storage, sludge incineration and thermal utilisation of screenings as well as composting operations and wood incineration plants
- Fats and oils produced in wastewater treatment plants, private households and the catering trade
- The utilisation of liquid and solid fermentation residues from the biodigestion plant (from its commissioning in 2025)
- The previous export of raw wood chips, green cuttings, fine screenings
- Food waste exports from private households, catering and retail

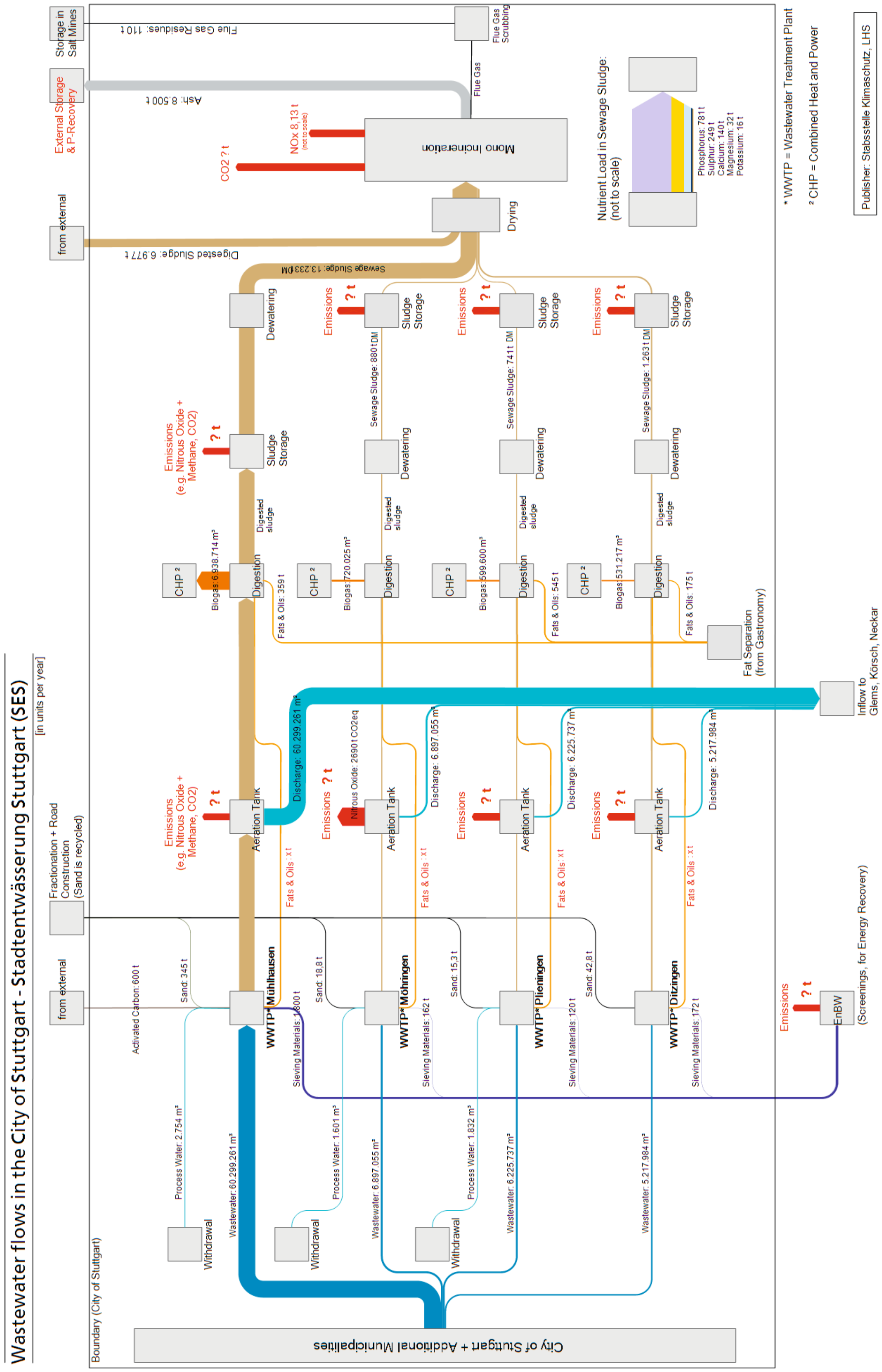


Fig. 4: Material flow diagram of Stuttgart Urban Wastewater Management with a focus on material flows that are relevant for bioeconomic processes and greenhouse gas emissions. This is a highly simplified representation that does not show all emissions and material flows from Stuttgart's four wastewater treatment plants. Material flows with high utilisation potential are highlighted in red.

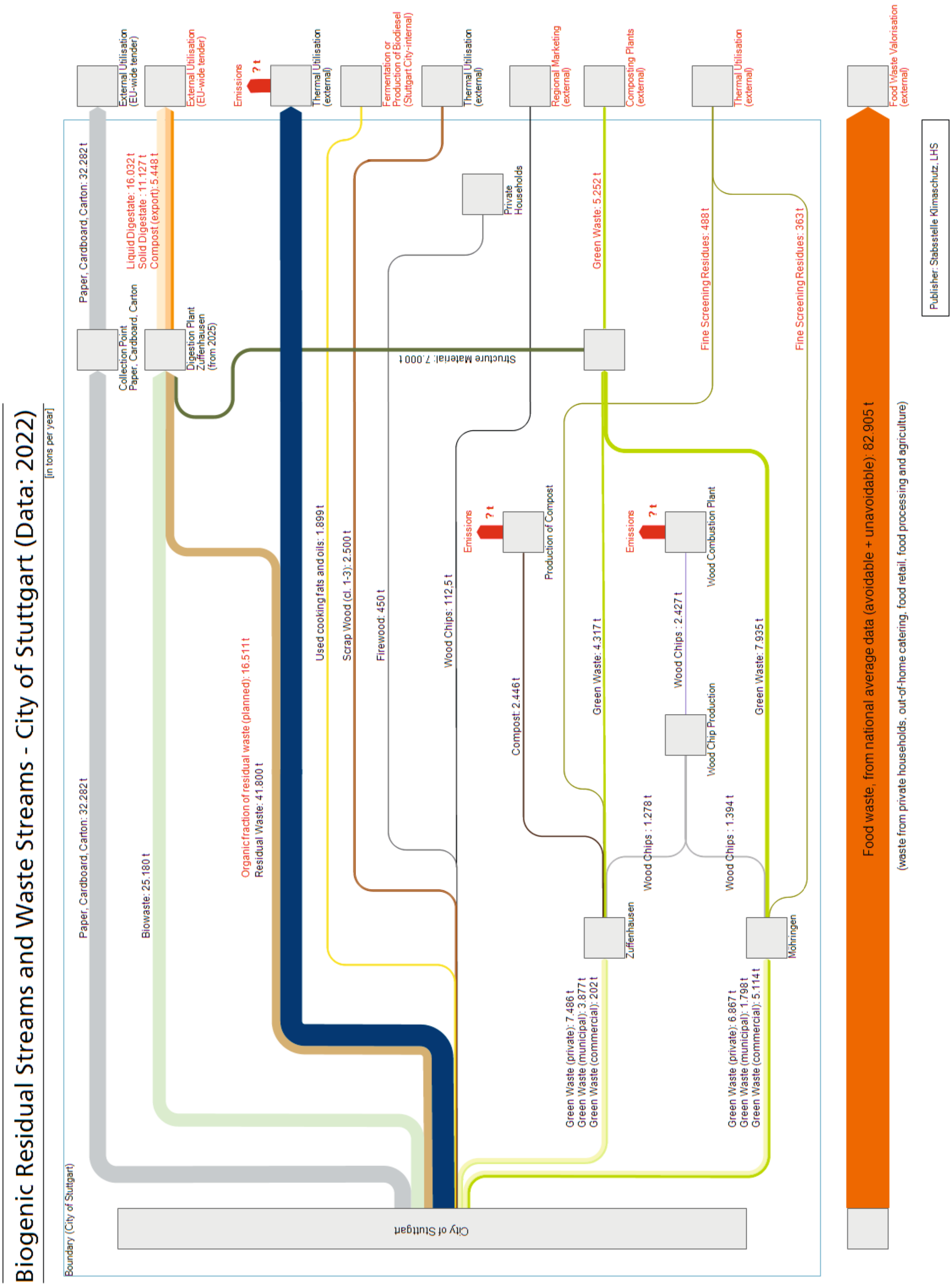


Fig. 4.1: Material flow diagram of biogenic substances in LHS. These material flows are managed by Stuttgart Waste Management and the LHS Municipal Landscaping, Cemetery and Forestry Authority. This is a highly simplified representation. Material flows with high utilisation potential are highlighted in red.

Potential analysis

The circular bioeconomy offers great potential for managing resources more sparingly within the limits of natural capacities. Alongside the technical cycle, it forms one of the two cycles of the circular economy. In the technological cycle, products are maintained, reused and refurbished over several cycles - long before they are recycled to a high standard.

"What is not emitted today does not have to be bound by energy-intensive and costly CDR in the future."

In the biological cycle, which is the focus here, material flows of natural origin are considered, for example wood and green waste, but also biological residues such as sludge, biowaste or fermentation residues. The aim of the bioeconomy is to replace fossil raw materials with renewable ones and to keep them in the cycle for as long as possible. As a result, CO_2emissions are minimised too. There is also the possibility of generating urgently needed negative emissions (see chapter 3: Negative emissions & carbon sinks) by means of bioeconomic processes.

Based on the material flow analysis carried out, specific utilisation potentials were identified within Stuttgart city. At this point, we wish to emphasise once again that this analysis only relates to material flows in the working area of the respective municipal offices and in-house operations in Stuttgart. Industry, the construction sector, food retail and catering were not included within the scope of the project.

DIRECT CO_2 EMISSIONS FROM MUNICIPAL FACILITIES

CO_2 point sources are places - often industrial production facilities or incineration plants - where CO_2 escapes into the Earth's atmosphere in higher quantities and concentrations. As regards municipal facilities, these are combined heat and power stations of wastewater treatment plants as well as biomass, sludge, waste incineration and biofermentation plants.

In principle, the CO_2 emitted at these points should be minimised. In the event of unavoidable residual emissions, CO_2 capture may be an option due to the increased concentration at these point sources. However, this is associated with high technical, energy and financial costs, meaning that it should only be considered as a last resort.

If capture is used, the CO_2 can either be utilised (Carbon Capture and Utilisation, CCU) or stored for the long term (Carbon Capture and Storage, CCS).

If sufficient renewable electricity is available, CO_2 can be converted into climate-neutral fuels using power-to-X technologies, for example. For reasons of efficiency, the fuels obtained should be used primarily in areas where defossilisation is technically more difficult, such as agriculture, heavy goods vehicles and air traffic (Measure 8.5). Alternatively, the captured carbon for C1 hydrocarbons can be used to produce bioplastics that replace fossil-based plastics.

Due to the high cost of CO_2 capture and the risks associated with CO_2 storage in particular, which have not been conclusively clarified, the other potentials listed below should be prioritised. However, the field of action should continue to be monitored, particularly with a view to further technical developments.

WASTEWATER TREATMENT PLANT EMISSIONS

Previously unknown quantities of methane and nitrous oxide are produced at the wastewater treatment plants in and around Stuttgart. The main focus here is on unquantified emissions from the aeration tank and sludge storage. The GHG impact of methane is 25 times (nitrous oxide is 265 times) higher than that of CO_2.

The smaller Möhringen-based wastewater treatment plant was equipped with measurement technology from Variolytics GmbH in 2023. Current results confirm measurement readings from wastewater treatment plants in Switzerland and put the actual nitrous oxide emissions at around twice the emissions that were previously measured via the nitrogen load (an outdated but widely used method for determining N_2O). Consequently, the European Union has also reacted and included direct emissions of nitrous oxide and methane and their monitoring in the new version of the Urban Waste Water Treatment Directive (European Union 2024). As far as we know, the annual nitrous oxide emissions in Möhringen (population equivalent of 0.16 million) amount to approx. 2,960 tonnes of CO_2e.

The Mühlhausen wastewater treatment plant is the largest wastewater treatment plant in Baden-Württemberg (population equivalent of 1.2 million). The emissions there will amount to a multiple of the emissions from the Möhringen wastewater treatment plant, so the cost-benefit balance here is promising.

The first step is to record the quantity of emissions at the Mühlhausen wastewater treatment plant. As a second step, these emissions are to be minimised through effective measures (Measure 2.1).

FOOD WASTE

On average, around 11 million tonnes of food waste are produced in Germany, around half of which could be avoided (Schmidt et al. 2019). Statistics cover primary production, food processing, trade, take-away food and private households. When based on the City of Stuttgart (approx. 633,000 inhabitants), this results in a usable potential of approx. 82,900 tonnes of food waste. It should be noted here that parts of this are already included in the material flows of the AWS (biowaste and residual waste; total organic content approx. 40,500 tonnes) presented in the material flow diagram. All food waste that is not processed by AWS leaves the city via service providers and could, in future, be utilised locally for materials and energy.

The first priority is to massively reduce avoidable waste in the future (Measure 8.7). The remaining, unavoidable food waste could be used in a variety of bioeconomic applications, provided that it is disposed of properly and made available to the AWS recycling companies. One possible area of use here would be local material and energy utilisation in the form of fermentation (Measure 4.3; a bio-fermentation plant managed by AWS is currently being planned). Electricity could be generated from the biomethane and waste heat thereby produced. Organic fertilisers could be produced from the liquid fermentation residues. Fibre materials for e.g. insulation materials in the local automotive industry would be a possible use of the solid fermentation residues. Another use of the solid fermentation residues is to convert them into certified biochar, which not only produces a high-quality substrate, but also the biochemical possibility of producing CO_2-negative biofuels (Siekmann 2024).

Another possible area in the future could be material upgrading via insect biorefineries or aquatic farms. These produce high-quality oils, fats, proteins and biopolymers as well as a high-quality organic fertiliser, which, in turn, can be used in urban farming systems.

WOOD CHIPS, GREEN WASTE AND FINE SCREENING MATERIAL

Green waste, of which roughly 5,250 tonnes out of the approx. 25,300 tonnes delivered to the collection points in the city are tendered for composting throughout the EU, and approx. 2,440 tonnes are composted in the city. 850 tonnes of fine screen material are thermally recycled externally. 112 tonnes of wood chips are exported from central Stuttgart. Furthermore, approx. 2,427 tonnes are burned as wood chips in wood-fired systems.

The most important utilisation potential is green waste. If this valuable raw material were to remain in the city, transport emissions could be reduced and, above all, the local potential for material and energy utilisation could be exploited. Here, Stuttgart has the opportunity to create negative emissions within the city with previously exported biomass quantities, a topic that will become increasingly important in the future in order to compensate for residual emissions, the emissions gap (United Nations Environmental Programme 2023). The best possible use under the premises of economic efficiency, legal regulations and climate friendliness still needs to be analysed in detail.

It is theoretically possible to process some of the biomass delivered to the green waste collection centres in a pyrolysis plant instead of composting it. Pyrolysis refers to various thermochemical conversion processes in which organic compounds (starting materials such as municipal green waste) are broken down at high temperatures. The resulting gases and waste heat can be utilised as local heat. Furthermore, certified biochar is produced as a heat source, in which around 50% of the carbon from the source material remains bound for several centuries (high permanence) and can only be decomposed extremely slowly using microbes (EBC 2023). Certified biochar is cited by the IPCC in a special report (IPCC 2022) as a promising negative emissions technology (NET).

When considering whether and what quantities of green waste are suitable for local pyrolysis, it is important to consider, among other things, how much CO_2 can be stored in the long term and what quantities of climate-neutral energy can be generated in contrast to comparable technologies, especially wood-fired systems. Based on the Stockholm model (see Fig. 5), 1.46 tonnes of CO_2 can be stored in the long term, for example, by planting 1.8 m^3 of biochar. This is roughly equivalent to the C storage of two beech trees growing for at least 80 years. The potential of a single tree planting with biochar thus corresponds to the annual carbon sink potential of around 120 newly planted beech trees (see Appendix Carbon Sinks Portfolio). The biochar produced in the certified pyrolysis process can be used to enhance green

Locally produced, EBC-certified biochar from Stuttgart green waste spaces in the City of Stuttgart, as biochar increases the water storage capacity of soil and also improves the availability of nutrients in the soil (Measure 1.1). The Stockholm model offers the ideal prerequisite for the growth and long-term survival of young trees as well as for the restoration of older trees in Stuttgart. It can be assumed that an optimised tree trench (planting pit in the Stockholm model) greatly increases a tree's chances of survival and thus avoids cost-intensive replanting. Biochar can also be used as a substrate in green roofs and façades (Measure 8.1) or as an additive in concrete (Measure 5.1). In the latter instance, the carbon footprint of concrete can be reduced by 25% with an admixture of 1% biochar (see Appendix Carbon Sinks Portfolio). *The Stockholm model is already being practised by the LHS Municipal Landscaping, Cemetery and Forestry Authority with locally produced biochar, and the aim is to scale it up (Measure 1.1).*

If the above material flows did not leave the city but were pyrolysed locally, this would result in an annual sink potential of approx. 3,100 t CO_2 (850 t fine screening material corresponds to approx. 500 t CO_2; 5,200 t green waste corresponds to approx. 2,600 t CO_2; 112 t raw wood chips corresponds to approx. 65 t CO_2; (see details in Appendix 2)). In order to achieve the same C-sink performance solely through tree planting, 250,000 beech trees would have to be planted every year.

In the production of compost carried out in Stuttgart to date, around 30% of the carbon escapes as CO_2 and other climate-relevant gases. Compost also offers only comparatively short-lived carbon storage, meaning that it is completely released after mineralisation of the compost (permanence depends on the source material, microbiome and climate).

In general, material utilisation is preferable to purely energetic utilisation (combustion) of biomass, as a large proportion of the carbon atoms produced during combustion today will have to be separated from the atmosphere in the future – regardless of whether it comes from burning wood or a fossil fuel. What is not emitted today does not have to be bound by energy-intensive and costly CDR in the future.

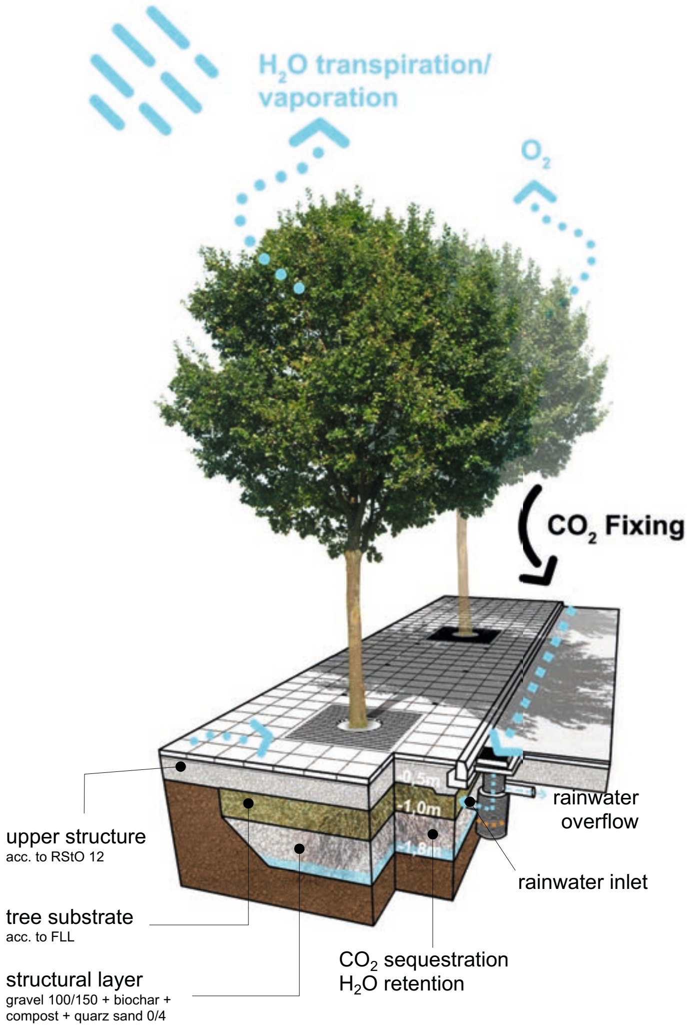


Fig. 5: In addition to an effective carbon sink, the Stockholm model offers an optimised tree location, which increases the vitality and climate resilience of urban trees.

FATS AND OILS

In the wastewater treatment plants, fats and oils arriving in the wastewater are intercepted and passed on to the digestion process for energy utilisation. Oils and fats from the catering industry are currently not collected centrally, but are managed by private service providers. Separated fats and oils from Stuttgart's food and beverage industry are delivered to three of the four wastewater treatment plants for energy recovery in the digestion process, or they are transported outside the city border. The quantity delivered by the service providers to the wastewater treatment plants amounts to approx. 1,070 tonnes per year. The amount of fats and oils that leave central Stuttgart via service providers has not been determined, but should be seen as a lost resource due to its high material and energy-related utilisation value.

A central collection centre could be used to recycle fats and oils from private households and parts of the exported tonnages. One example of this would be the production of biodiesel, which could be used as a climate-neutral fuel in the City of Stuttgart's own fleet of police, fire, ambulance and refuse lorries (Measure 4.2). It is also possible to feed these unused quantities of material into the digestion process of the wastewater treatment plants for local energy-related utilisation. The comparison of the potential as bio-diesel or energy source for fermentation requires a specific environmental assessment. It is clear that local utilisation of the energy-rich material flow is preferable to export.

SEPARATION OF ORGANIC RESIDUES IN RESIDUAL WASTE AND THEIR UTILISATION IN AN ORGANIC WASTE FERMENTATION PLANT

Around 30% of residual waste is organic waste (approx. 16,500 tonnes; AWS survey in 2017). So far, these have been channelled into external thermal recycling and are therefore lost as materials. An idea would be to divert this organic portion of the residual waste to the local fermentation plant in order to generate electricity and local heating (Measure 4.1). This means that the fermentation residues can also be utilised as a material (see "food waste").

LOCAL UTILISATION OF FERMENTATION RESIDUES FROM THE PLANNED FERMENTATION PLANT IN ZUFFENHAUSEN

The biomass fermentation plant in Zuffenhausen is scheduled to go into operation in 2025. The plant is designed for a maximum capacity of 40,000 tonnes of biomass. At maximum capacity, approx. 16,000 tonnes of liquid digesttate, 11,100 tonnes of solid digestate or approx. 5,500 tonnes of compost remain after the fermentation process is complete. It is planned to put these out to tender throughout the EU and exported outside the City of Stuttgart. However, this material flow also contains important nutrients and carbonaceous components that could be utilised in Stuttgart (Measure 4.3). Local utilisation would reduce transport emissions. Compost production is planned from the solid part of the digestate. On average, 30% of the carbon contained in this is emitted through decomposition. An alternative use such as pyrolysis would reduce emissions, create long-term carbon sinks and still produce a valuable plant substrate (see Appendix: Carbon Sinks Portfolio). One possibility would be to continue the ongoing market exploration in order to utilise the material flows as climate-neutrally or even climate-negatively as possible (Siekmann 2024).

WASTE WOOD

Stuttgart produces 2,500 tonnes of class 1-3 waste wood. Class 1 comprises untreated waste wood, class 2 treated waste wood and class 3 contaminated waste wood. To date, all waste wood has been utilised for thermal energy generation outside the city. Transport emissions could be reduced by thermal utilisation within central Stuttgart. In future, it would also make sense to utilise waste wood as a material in order to bind the carbon in the waste wood over the longer term. However, this only applies to uncontaminated waste wood.

IRRIGATION WATER

The Mühlhausen, Möhringen and Plieningen waste water treatment plants currently supply 6,100m^3 of process water annually to the watering vehicles of the LHS Municipal Landscaping, Cemetery and Forestry Authority for watering the greenery in the city. A decentralised watering water supply would save distances for the watering vehicles in central Stuttgart. For example, large cisterns could buffer heavy rainfall events and store the precipitation locally where it is needed later. Drip irrigation is another technical option for irrigating green spaces as efficiently as possible and adapted to climate changes (Measure 8.6).

PHOSPHORUS RECOVERY

Phosphorus is a finite resource and, at the same time, an essential nutrient for all living organisms (Montag et al. 2014). Phosphorus is currently mainly mined in Morocco, chemically processed and imported as a fertiliser for agriculture. With approx. 780 tonnes of phosphorus in the annual sludge load of all four Stuttgart wastewater treatment plants, phosphorus is a very relevant material flow. The sludge from the four Stuttgart and other external waste water treatment plants is currently collected and incinerated at the main wastewater treatment plant in Mühlhausen (in 2022, the amount incinerated totalled 22,668 tonnes of DM). Phosphorus contained in the sludge ash is exported with the ash from central Stuttgart. Phosphorous recovery will be required by law from 2029. However, an economically and ecologically viable technology for recovery is not yet available. LHS is currently working with the Karlsruhe Civil Engineering Department and Zweckverband Steinheule (Ulm/Neu Ulm) to conduct a market survey on the state of technology (see Municipal Council Document 175/2022). The plan is to collect the sludge ash produced and recover the phosphorus at a later date in large-scale phosphorus recovery plants.

As the energy-intensive phosphorous recovery costs are likely to far exceed the ash storage costs in the near future, other methods also need to be considered. The availability of phosphorus to plants ("vitrification in mono-combustion") should be taken into account in addition to the cadmium contamination in the phosphorus. Sewage sludge pyrolysis, with its enormous potential as a C sink, has been tested and is working in pilot projects (EBI, 2023).

CENTRALISED PROCUREMENT

As regards Stuttgart's central procurement, there is untapped potential to both minimise emissions in the production and transport of goods and to maximise product service life. Specifically, circular procurement could be increasingly promoted, which favours the use of biological source materials and also increases the product life cycle (Measure 3.1). Besides drawing up a negative list of products that should no longer be procured (e.g. disposable tableware), it would make sense to select alternative products according to bioeconomic criteria. This not only reduces the amount of waste, it also favours bio-based raw materials over petroleum-based materials (Measure 3.2). Adapting the procurement regulations to include climate- and resource-friendly aspects would be expedient (Measure 3.3).

CONSTRUCTION INDUSTRY

The construction sector was excluded from this study, as the focus was on biogenic material flows in the City of Stuttgart, and no reliable figures were available for biogenic materials in the construction industry. The construction sector will also be analysed in more detail in the circular economy strategy currently being developed by LHS. The results of a preliminary study showed that 4.0 million tonnes of material (especially stone, earth and wood) are used in construction in Stuttgart annually. This corresponds to over a quarter of all the material that goes to Stuttgart every year and is associated with as yet unquantified quantities of greenhouse gas emissions. Initial positive experiences have already been made in Stuttgart with recycled concrete, which can reduce GHGs by an average of 7% (WWF 2019) and help conserve resources. The cement content is the main reason for the poor greenhouse gas balance of concrete. The energy-intensive processes and chemical reactions involved in cement production generate considerable amounts of GHGs.

A new topic that combines the bioeconomy with the circular economy in construction is the so-called climate concrete, in which biochar is added to the concrete mix. Adding 1% biochar to concrete can offset the CO_2 footprint by up to 25%. The carbon is bound in the concrete for a long time and can be seen as an effective carbon sink. Market research and the initiation of a suitable project for the pilot testing of the use of biochar in concrete is dealt with in Measure 5.1.

OVERVIEW OF MEASURES

In a broad participation process, 22 measures were developed. The basis for this was a kick-off workshop with the relevant LHS municipal departments and in-house operations to analyse the potential and develop measures. The options developed were then reviewed by the relevant specialist departments and finalised in bilateral consultation with the ZirBioS project management.

The following table lists all measures according to responsibility. The detailed profiles of measures can be found in the appendix to this strategy.

Reinventing Society and the Wire Collective have created a vision for Stuttgart's marketplace for the illustrated book "Zukunftsbilder 2045".

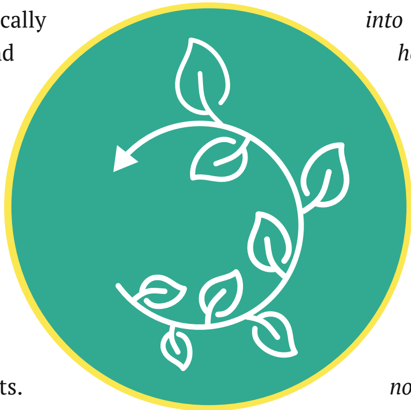
MEASURE NO.:	MEASURES
1.1	**LHS MUNICIPAL LANDSCAPING, CEMETERY AND FORESTRY AUTHORITY**
	Stockholm model for planting new roadside greenery & cross-regional exchange
	STUTTGART URBAN WASTEWATER MANAGEMENT
2.1	Reduction of greenhouse gases in wastewater treatment plants; creation of a data basis
2.2	“No wet wipes in the loo" campaign. Remove the "flushable" and "dispose of in toilet" labels
2.3	Reduction of GHGs by purchasing powdered activated carbon
	HUMAN RESOURCES DEPARTMENT
3.1	Promoting circular procurement and utilising (biological) resources throughout the product life cycle
3.2	Integration of bioeconomic criteria in the development of a negative list in procurement
3.3	Adaptation of procurement regulations to include climate- and resource-friendly aspects
	STUTTGART WASTE MANAGEMENT
4.1	Reduction of organic waste in the residual waste bin
4.2	Decentralised collection points for fats and oils
4.3	Valorisation of solid and liquid digestate
4.4	Climate-friendly cat litter
	BUILDING DEPARTMENT
5.1	Reduction of the CO_2 footprint in concrete / cement
	CIVIL ENGINEERING DEPARTMENT
6.1	Use of eco-asphalt and recycled asphalt
	OB/82 ECONOMIC DEVELOPMENT
7.1	Networking of production and research infrastructure for start-ups
	S/OB CLIMATE ACTION OFFICE
8.1	Continuous updating of the bioeconomy strategy and monitoring of measures
8.2	Direct measures ZirBioS: map of bioeconomic players, networking workshops, carbon sink potentials
8.3	Develop online platform pilot projects in Stuttgart
8.4	Municipal green waste pyrolysis: analysing best practice examples and implementation options transferred to LHS
8.5	Analysing potential and setting up an implementation project for carbon capture in incineration plants
8.6	Decentralised irrigation water supply
8.7	Avoidance of food waste and material utilisation
8.8	Roof and façade greening in combination with alternative substrates (C-sinks)

Table 1: Measures according to responsibility

Conclusion

As explained in detail above, the greatest potential lies in the local processing of the aforementioned material flows. In accordance with the Circular Economy Act, material utilisation is preferable to energy-related utilisation. Green waste, wood chips and solid fermentation residues, in particular, should be utilised locally in the medium term for heat, energy and substrate production (biochar) using pyrolysis technology. Not only does the limited raw material biomass remain in central Stuttgart, there is also a great future-oriented opportunity to generate negative emissions (see chapter 3 Negative emissions & carbon sinks) locally. In the long term, CO2 capture should take place in all existing Stuttgart incineration plants.

Implementing the potential identified is already underway in some areas. In other areas, an intensive detailed investigation will be necessary. If we succeed in exploiting the potential, the following could be achieved:



Biomass is increasingly being used in roadside greenery, on roofs and façades, but also in tiny forests in Stuttgart. Concrete and tarmac give way to urban greenery. No valuable biogenic material flow leaves the City of Stuttgart. The urban biomass is collected centrally during maintenance work and fed into a local pyrolysis plant. The resulting waste heat is fed into the local heating network, and the pyrolysis gas is treated (e.g. carbon capture). The locally produced biochar is used for planting new trees, renovation of trees as well as parks and for greening roofs and façades. The CO_2 certificates for the use of biochar and urban biomass are accounted for in Stuttgart and dual postings by external service providers is ruled out. In the medium term, scaling will not only compensate for residual emissions that are necessary to achieve net zero by 2035, it will also generate the urgently needed negative emissions. The combination of the pyrolysis process with a biofermentation plant takes place depending on the prioritisation. Solid fermentation residues from this potential biofermentation plant are used to produce fibre materials for the local automotive industry.

Additional topics

The following topics were discussed, but could not be finalised as part of the funding project or translated into concrete action plans. These topics will need to be discussed in detail in the future and appropriate measures derived.

- Reduction of greenhouse gases in composting facilities
- Improved waste separation in municipal operations (municipal departments and in-house operations)
- Use of biogenic materials in construction - de-bureaucratisation, uniform standards (collated under *Entlastungsallianz bei Land-/Städtetag*)
- Green IT; reducing GHGs by optimising software
- Cloth nappy cleaning system with possible energy recovery, for retirement homes and private households
- Encouraging the use of reusable nappies rather than disposable nappies
- Climate-friendly wine in Stuttgart: carbon sink potential, regional recycling programmes
- Climate asphalt and climate concrete with strong scaling
- Check methane plasma analysis site

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The appendix to this strategy contains

- Appendix 1: Catalogue of measures
- Appendix 2: Carbon sink portfolio study

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