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Deliverable 1.6 Progress in set up of pilot regions

Closing the gap between fork and farm for circular nutrient flows

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Table of Contents

Table of Figures

Table of Tables

Acronyms

CBS	Copenhagen Business School
CMC	Component Material Category from FPR
CO_2	Carbon dioxide
DM	Dry Matter
DSS	Decision Support System
EC	Electrical Conductivity
EU	European Union
EVH	Ecovillage Hannover
FSB	Feststoffbehälter - Sealed Container for solid sanitary waste
FPR	Fertilising Products Regulation (EU) 2019/1009
GRL	Governance Readiness Level
IBC	Intermediate Bulk Container
IoT	Internet of Things
KPI	Key Performance Indicator
KWB	Kreiswerke Barnim GmbH
NaClO	Sodium hypochlorite
N_2O	Nitrous oxide
NPK	Nitrogen, Phosphorus, Potassium
P.E.	People Equivalent
ROSS	Ressource Oriented Sanitation Systems
SFT	Smart Fertigation Tool
SLU	Swedish University of Agricultural Sciences
S360	Sanitation360
TRL	Technology Readiness Level
UDFT	Urine Diverting Flush Toilet
UDDT	Urine Diverting Dry Toilet
UV	Ultraviolet radiation
VN	VunaNexus
WWTP	Wastewater Treatment Plant
WP	Work package

1 Executive Summary

The focus of this deliverable, integral to the P2GreeN project, is to provide a comprehensive update on the progress of Task 1.1: Set up, operation, demonstration, and validation in pilot regions. The pilot regions are located in Gotland, Sweden, region Hamburg-Hannover, Germany and La Axarquia region, Spain, led by the pilot regions coordinators Sanitation 360, Ecovillage Hannover, and Bioazul. Our report is enriched with crucial outcomes, including progress tables for Key Performance Indicators and Governance Readiness Levels, pilot region fact sheets, and executive project plans represented through Gantt Charts. The deliverable sets the stage for the Demonstration Report due in November 2025, showcasing validated prototypes from the three case studies (D1.1).

The establishment and operationalisation of three P2GreeN pilot regions serve as dynamic environments for adapting, demonstrating, and maturing innovative circular nutrient flows keeping N & P cycles in balance. The primary objective is to create a nutrient cycle between water-waste infrastructure, that is connecting the nutrient output of urban areas with agricultural nutrient demands in an ecologically safe way, reducing the pollution from conventional sanitation and fertilisation. The pilot regions implement diverse systematic innovative technological and system approaches to convert human sanitary waste into safe bio-based fertilizers for agricultural production, validated under real-life scale-up conditions.

As of this report, two pilot regions—Gotland, Sweden and La Axarquia, Spain—have operationalized different technology systems, while Hamburg-Harburg has significantly matured towards finalizing implementation planning and operationalization. The technology's full implementation is slated for March 2025 (Milestone 5), with the planning phase concluding with this report (Milestone 1).

The Swedish pilot region of Gotland: The urine-drying system provided by Sanitation360 is a portable, off-grid design that can process the urine on-site in the toilets. The system has been optimised and rolled out at various locations on the island of Gotland using mobile toilet provider Touch Down's existing network and maintenance contracts. In particular, this includes public toilets in the city of Visby and nearby facilities. Subcontracted farmers have used the pelletised recycling fertilizers in 2023 field trials (3-6 ha) with barley on Gotland, showcasing a very convincing fertility effect on the crops. The local brewery Gotland Bryggeri is validating the suitability of barley grown with urine-based fertilizer for beer production and, within the project time, produce commercially available beer to close the value chain.

The German pilot region of Hamburg-Hannover: The housing cooperative ecovillage hannover has planned for the installation of commercially available ceramic urine diverting flush toilets (type: LAUFEN save!) for 230 persons and plans to collect approximately 100 m³/y urine in cooperation with Goldeimer. The urine shall be

processed at the ecovillage in a central facility using the urine treatment system provided by VunaNexus, who will also take care of necessary adjustments, operation and maintenance of the system. The Aurin® fertilizer will be marketed by VN. Goldeimer has collected dry toilet contents from festivals, allotment gardens and off-grid nature tourism destinations in the 2023 season. A thermophilic container-based composting plant for faeces is being set up, further automating the technology developed by Goldeimer's network partner Finizio, and operated by Goldeimer on the Vagtshoff farm in lower saxony near Hamburg. The Vagtshoff farmers provide industrial waste heat and biochar for the composting facility, as well as the agricultural area (6 ha) for fertilizer application. Both faecal compost (~40 t[dm]/yr) and Aurin® fertilsers (9,5 m^3) will be used to grow agricultural crops. The field trial has been registered with the local authority, whereas the construction of the composting facility has a permit pending.

The Spanish pilot region of La Axarquia: Bioazul has installed a water reclamation plant to treat and transform municipal wastewater from the wastewater treatment plant of Algarrobo into nutrient-optimised irrigation water for customised agricultural application. TROPS is yet applying the product to avocado and mango plots (120 trees total) in an optimised way, to be supported by a Smart Fertigation Tool, technology under development by AgriSmart Data. The refinement by the smart addition of nutrients, tailored to the nutritional demand of the specific crop, is in focus. It is key added value for producers to mainstream the reuse of wastewater resources for crop fertigation.

2 Background

In this chapter, the nexus of the state of the art of human sanitary waste management and geochemical flows such as nitrogen (N) and phosphorous (P) is described as the given framework under which the three pilot regions operate. The maturation of P2GreeNs innovations in the pilot regions is contextualised with the current trends of sanitation systems, N & P nutrient flows and agronomy.

2.1 Detachment of the nutrient circles in the 20th century

In Paris, half of the city's urine was recycled and made use of only a century ago (Esculier & Barles, 2020; Ferguson, 2014). However, with the improvement of many country's wastewater treatment facilities in the mid 1900s, the recycling of human excreta subsided (Esculier & Barles, 2020). There was also growing awareness about the connection between poor sanitary hygiene and the spread of diseases. A parallel development was the industrial production of mineral fertilizers ("green revolution"), where both trends combined effected a transformation of the sanitary system into a linear system. As a result, less and less resources from wastewater were reclaimed (Mårald, 2000; Spink, 1979). In 2021, over 80 % of Europe's urban waste waters were collected and treated in line with EU legislation, which means that a daily total of 108.85 million m³ of wastewater is collected by sewer-based sanitation systems and treated in one of the >20,000 municipal wastewater treatment plants (WWTPs) across the EU.

When it comes to wastewater treatment in the EU, recent estimates show that 95% of urban wastewater is collected, 88% undergoes secondary (biological) treatment and 86% undergoes further treatment where nitrogen and phosphorus is partially removed (European Commission, 2022). A WWTP deposits the nutrients found in wastewater by releasing nitrogen back into the atmosphere and extracting the phosphorus as well as other nutrients as excessive sewage sludge, which is disposed via different methods depending on the regional context (cf. **Figure 2**). No municipal wastewater treatment plant is 100% efficient in their removal of nutrients (Pistocchi et al., 2023). Additionally, the use of water as a transport media for the operation of flushing toilets and sewer systems, without water reuse, relocates regional freshwater resources to the oceans.

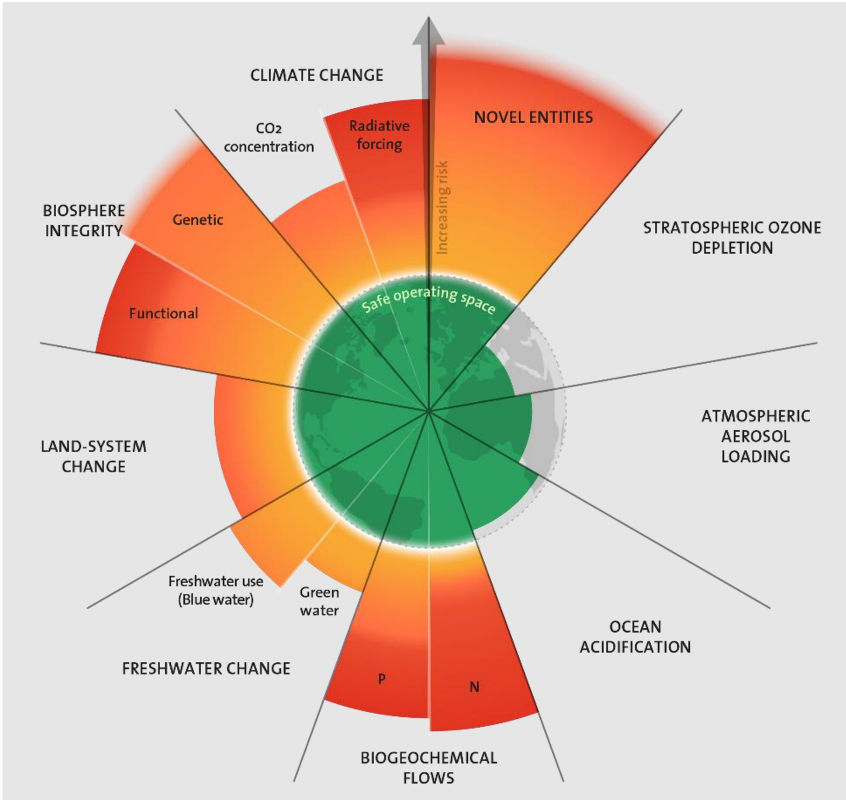


Figure 1. The 2023 update to the nine key planetary boundaries, of which biogeochemical N- & P-flows as well as novel entities and freshwater change have transgressed the safe operating space. Licensed under CC BY-NC-ND 3.0. Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023.

Developing a circular economy focused on recycling plant nutrients in the form of human excreta back to agricultural fields would reduce the current dependence on fertilizers derived from non-renewable resources (Ramírez & Worrell, 2006). It could also improve crop yields, for example in sub-Saharan Africa where fertilizer application is low (FAO, 2015), and protect marine ecosystems in many places by limiting the flow of excess nutrients to surface waters (Steffen et al., 2015).

With large amounts of water, also large amounts of nutrients and novel entities pass the WWTP and with its effluent are drained from cities to water bodies. Thereby the sanitation system contributes to excessed planetary boundaries such as freshwater use, novel entities and biogeochemical N- & P-flows (cf. **Figure 1**). So called “death zones” - hypoxia areas of the oceans caused by eutrophication - play a significant role in the release of nitrous oxide (N_2O). The N_2O-production can be 10,000 times more than normally for sea water. This affects around 10 % of the water volume worldwide. Increasing death zones are resulting in increasing N_2O -emissions (Codispoti 2010), a greenhouse gas 297 times more potent than CO_2. In the Baltic Sea, for example, the death zones grew in the last 110 years from 5,000 to 60,000 km² (Carstensen et al. 2014).

The growing concern about the future availability of fertilizers has highlighted the need for reclaiming the nutrients that exist in our sanitation system (Harder et al., 2019). Like today's linear economy, big proportions of fertilizer flows follow a linear pattern where extreme amounts of nutrients are simply leaked into the environment (Chojnacka et al., 2020). However, recovering nutrients derived from wastewater and human excreta could advance the European "Farm to Fork" strategy, linking increasingly urban populations to rural agricultural land (Trimmer & Guest, 2018). A circular nutrient economy entails ensuring high recovery rates of nutrients and biomass from human waste, such as human excreta and food waste, and recirculating it back to agriculture (Harder et al., 2019). This would reduce the need for synthetic fertilizers, which require large amounts of fossil fuels to be manufactured (Glibert et al., 2014).

Raw materials to produce synthetic fertilizers are also being extracted at rates that are depleting global resources, such as in the case of phosphorus which is extracted from mining (Reijnders, 2014), whereas nitrogen is extracted from the atmosphere through the Haber-Bosch method (Menegat et al., 2022; Steffen et al., 2015). In 2022, global fertilizer demand reached almost 200 million metric tons, 110,8 of which was nitrogen, 50 was phosphorus and 39,1 was potassium (Statista, 2023a). Excessive or inefficient use of fertilizers lead to nutrient accumulation in water bodies, fostering primary biomass production (Jansson et al., 2019). This ends up depleting oxygen reserves, causing eutrophication which is devastating for marine life (Jansson et al., 2019). Despite already having breached the planetary boundary of biogeochemical flows, mainly due to our excessive use of fertilizers (Steffen et al., 2015), the global fertilizer demand is expected to increase to 208,3 million tons in 2026 (Statista, 2023b).

In the EU27, mineral fertilizers and manure make up >80 % of the nutrient sources for agriculture (cf. **Figure 2**). Animal manure production ranges above 1.4 billion tonnes of manure produced annually, of which >90% is directly applied to soils as fertilizer (Köninger et al., 2021). To achieve the European Commission's goals as declared in the European Green Deal (and its ancillary components such as the Farm to Fork Strategy and the Zero Pollution Action Plan), both fertilizer types must be reduced in production and application rates. In organic farming, organic animal manure is the main source of nutrients. However, the market share of organic meat is low (3.9% organic meat 2022). There is a lack of authorised nutrient sources for crop and fodder production (sewage sludge excluded due to contaminants) and it is therefore crucial to explore further local, sustainable and safe sources of nutrients.

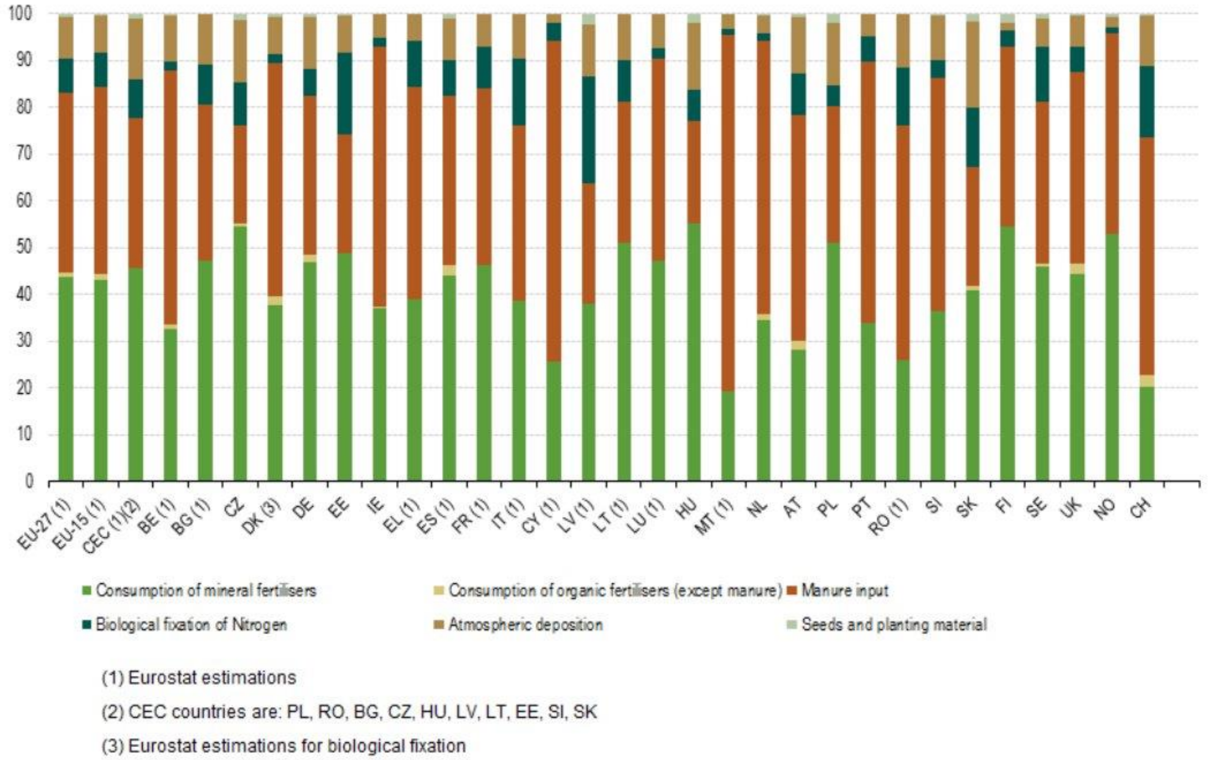


Figure 2. Distribution of N per pathway in the member states (Eurostat, 2020)

2.2 N- & P- emissions from current linear systems

Between 2005–2012, the nutrient load to European seas was 3,300–4,100 kt N/y of nitrogen and 260–300 kt P/y of phosphorus (Grizzetti et al., 2021). The majority of these are derived from mineral and manure fertilizers (71% N and 93% P). Together with atmospheric depositions (17% N), these can be considered the major diffuse inputs from human activities, whereas industrial and domestic waste waters (3,5% N and 5% P) are the major point pollution contributors to the accumulation of nutrients in European waters. As part of the European Zero Pollution Action Plan targets to deliver a 'near-zero water discharge' of pollutants.

The numbers of nutrients discharged from WWTP vary greatly between countries. In Sweden, total nitrogen emissions amount to 51 kt N/y (Naturvårdsverket, 2021). Simultaneously, 33% of the nitrogen load and 16% of the phosphorus load Sweden emits to the Baltic Sea is derived from municipal wastewater effluent (Jordbruksverket, 2022). In Spain, WWTPs receive approximately 67 kt N/y, out of which 73% (49 kt N/y) is discharged into water bodies with the wastewater treatment plants effluent (Mayor et al., 2023). In Germany, thanks to wide application of tertiary treatment, the effluent contains only 19 % of the received N, but the specific annual per capita load of N discharged annually is comparable to that of Spain (cf. **Table 1**).

Table 1. Nitrogen release data for each pilot regions country

Pilot region / parameter	Annual N release total [kt N / y]	Annual N release specific [kg N / capita•y]	Annual N release to water bodies [kt N / y]	Share of agriculture (of N release to water bodies) [%]	Share of wastewater (of N release to water bodies) [%]	N from wastewater cumulated [kt N]
Sweden	51	5.0	15	47 %	33 %	13.7
Germany	1,547	18.3	585	79 %	14 %	106.0
Spain	913	18.8	779	93 %	6 %	47.0

Data from SRU, 2015; Tuholske et al 2021; Naturvårdsverket, 2021; Jordbruksverket, 2022; Mayor et al., 2023

The cumulative burden of Germany and Sweden is significantly higher than that of Spain. In an international study of global total nitrogen input via wastewater (6.2 Tg N) by Tuholske et al., 2021, Germany (#10) and Spain (#19) are ranged both in World's Top 20 (cf. **Figure 3**).

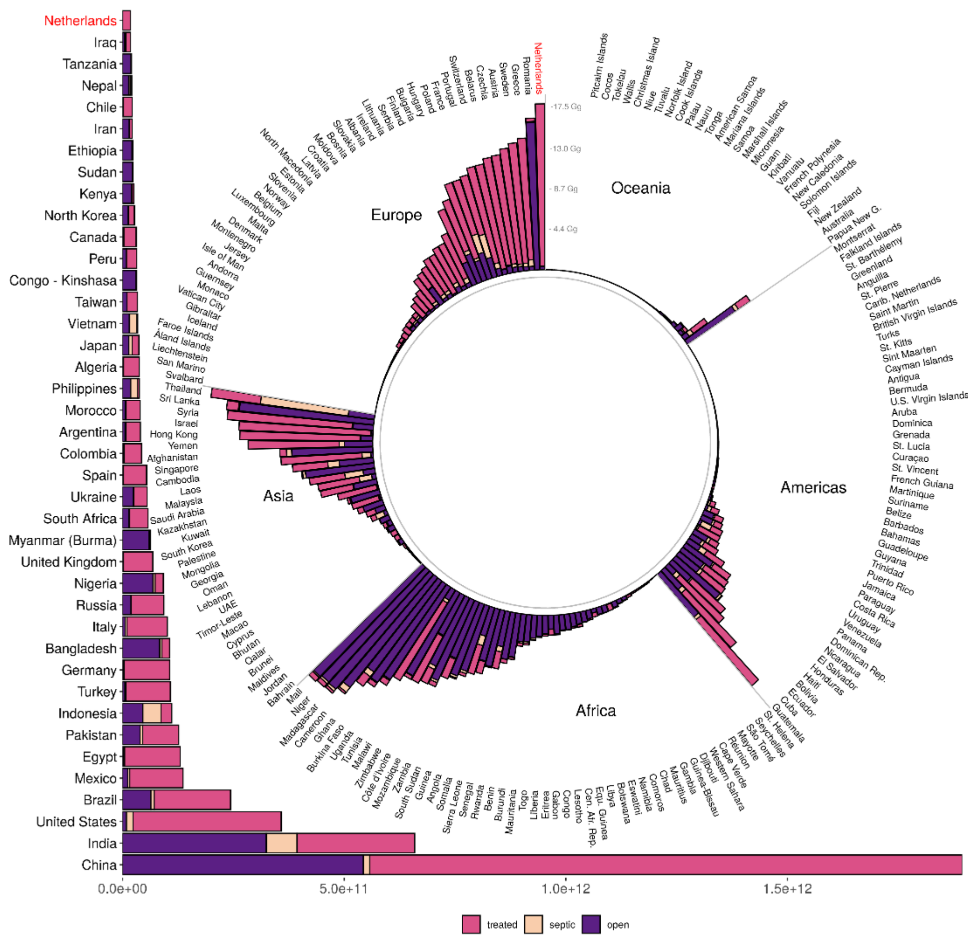


Figure 3. Germany (#10) and Spain (#19) are both in the Top 20 of global cumulative total nitrogen input via wastewater (6.2 Tg N) (Tuholske et al. 2021).

2.3 Contaminants contained in wastewater

Heavy Metals are less of a concern in urine-derived fertilizers, than fertilizers derived from animal manure and conventional mineral fertilizers (Jönsson 2011). Heavy metal concentrations found in human urine are far below the Swedish limit for land application (Jönsson et al., 1997) and well below the levels in other biologically derived fertilizers (Hammer & Clemens, 2007; Jönsson et al., 2004).

Pathogens are potentially found in urine, mainly from faecal cross contamination; however, the produced urine fertilizer can be used directly as any potential pathogens are eliminated due to the harsh environment (pH, low water content and heat).

Pharmaceutical residues are frequently discussed when considering urine-based fertilizers but are already a problem with lack of adequate sanitation and with conventional WWTPs. Pharmaceutical residues occur in very small quantities in wastewater, and they are difficult to detect and remove at WWTPs (Luo et al., 2014), which are usually designed to treat bulk substances (Larsen et al., 2004). After passing through the WWTP, pharmaceutical residues remain biochemically active in water and can alter the behaviour of aquatic animals (Van Donk et al., 2016; Brodin et al., 2013).

If instead the pharmaceuticals are applied to land (via re-use of excreta as a fertilizer), then we would ingest fewer compounds, compared to what we ingest via the drinking water today. A simulation study in Levén et al. (2016) found that one would have to eat carrots or potatoes every single day for over 5 000 years to get one dose of the most resilient pharmaceutical compounds (over 20 000 years for the less resilient). The same simulation study found that intake of pharmaceutical residues would be at least 10-fold higher through drinking tap water in Stockholm (Levén 2016). According to Vinnerås et al. (2008), several pharmaceutical substances are found in higher concentrations in animal manure compared to what can be expected in human urine. Overall, residual pharmaceuticals remaining in the fertilizer are too low of a concentration to be of a risk to humans. Saying that, there is still an uncertainty about the risk to the micro-biome of the soil.

2.4 Sewage sludge management

From the total amount of approximately 40 billion m³ of wastewater treated in the EU annually, approximately 10 million tonnes of sludge (DM) derive.

The cases of Germany and Sweden are special. In 1999, the Federation of Swedish Farmers (LRF) recommended that their members stop using sludge because of concerns about its quality, a recommendation that many farmers still follow to this day. A study by Wallenberg & Eksvärd (2018) found that 85% of Swedish farmers who are offered to use sludge decline, mainly due to worries about traces of hazardous substances in the sludge.Despite this, Sweden’s use of sludge has increased in recent years and in 2020, 34% of treated sewage sludge was recirculated back to agricultural land (SOU, 2020). This is largely thanks to the work of a WWTP certification called

Revaq which strictly limits the amount of pathogens and heavy metals that sludge can contain to be allowed as a fertilizer (Eurofins, n.d.). However, Revaq-certified sludge is only permitted for use in conventional farming (SOU, 2020).

In Germany, the novelation of the sewage sludge ordninance (AbfKlärV, 2017) limits the field application of sewage sludge significantly. By the year 2029 (> 100 kP.E.) and by 2032 (>50 kP.E.) respectively, treatment plant operators are obliged to recover phosphorous from sewage sludge. As the field application can in most cases not be matched with the new thresholds on pollutants, the mainstream path taken is the mono-incineration of sewage sludge. Exceptions to the obligation to recover P only exist for sewage sludge with low phosphorus concentrations (less than 20 g P per kg of sewage sludge (dry matter)).

How sludge is treated across Europe also varies greatly from country to country. Whilst Germany incinerates most of its sludge already today, Spain and Sweden are mainly applying it to land (cf. **Figure 4**). Looking at field application, improvements in management and application are needed to reduce the large amounts of nutrient losses through gas emissions, leaching and runoff.

In the past, high levels of heavy metals in sludge for agricultural use were an issue in terms of agricultural its negative impacts on both soil and human health. Even though these levels have decreased up to 10 times within the EU, partly due to the EU's Sewage Sludge Directive: Council Directive 86/278/EEC, heavy metals in sludge still pose a threat to our food system (European Commission, 2023c).

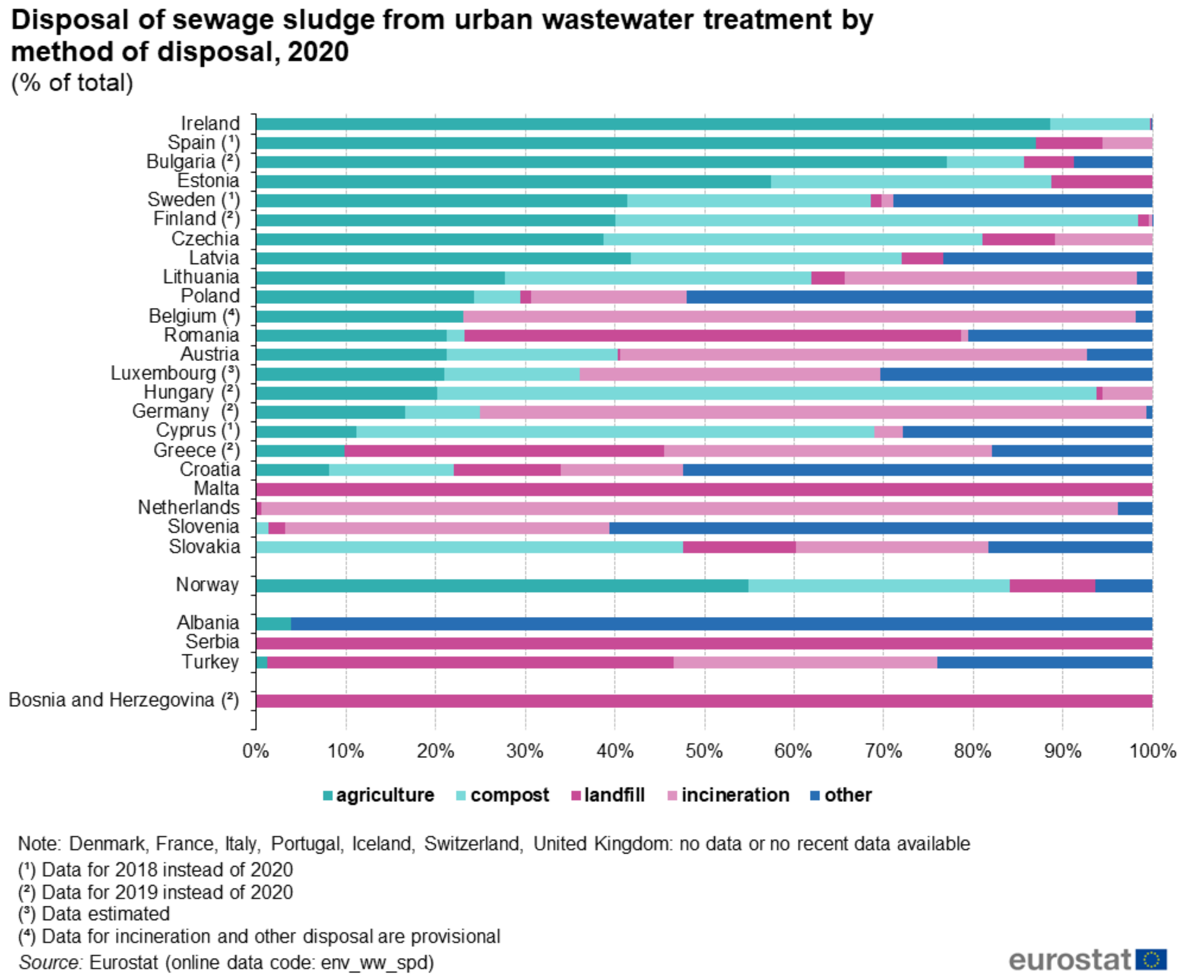


Figure 4. Disposal of sewage sludge from urban wastewater treatment by method of disposal in % of total (Eurostat, 2020).

2.5 Transformation approaches - from disposal to reclamation

With the sanitation system evolved over the past 150 years in the global north, problems of public health have been tackled effectively. Sanitation has quickly transformed to a water system and thereby has been decoupled from the nutrition system. For most municipalities in Europe, the sewage system incorporates the largest scale infrastructures which are constantly growing with every household connected and every treatment step added to the WWTP and sludge management. But the system lock-in is not only manifested in concrete infrastructures, but also in the mind of the user, as with the water closet the comfort and peace of mind for people has improved significantly.

Hence a transformation of the sanitation system to become sustainable needs to address these barriers and to provide answers how the existing system can be transformed.

The main drivers for a sanitation transformation in Europe are ecological, whereas globally the tier of sanitation justice must be added. For most societies in the world, the aspects of nutrient and water stress resilience are becoming relevant factors.

The P2GreeN solutions lever on various of these drivers. Advanced treatment for water reuse builds upon the lock-in of the water system and combines the reduction of emissions with resource reclamation for application as vital fertilizers for agricultural production.

Source separation provides system components that can be applied in various ways, from decentral to central it can be combined with the benefits of the sewer system whilst offering relief to it in terms of the needs for circular economy.

Source separation

In terms of toilets, source separation refers to the separation of human excreta as it enters the toilet. Therefore, the two very different compounds urine and faeces can be treated separately and in a more targeted manner. This is often implemented by using redesigned toilets or toilet attachments, such as urine diverting toilets. The separated urine can then be collected and treated separately, as it contains the largest proportion of valuable nutrients in our excreta, such as nitrogen and phosphorus, which have agronomic value (Simha et al., 2020b). Urine also contains the largest proportion of pharmaceuticals excreted (Lienert et al., 2007). Faeces also contains valuable nutrients and especially organic carbon which is also important for plant growth (Yadav et al., 2010). Faeces can be treated using various technologies, including composting toilets and anaerobic digesters, which can convert this organic mass into usable resources like compost, biochar, sludge fertilizer and biogas.

Nutrient recovery is one of the primary advantages of source separation as it offloads conventional WWTPs receiving a wastewater that is better balance between nitrogen and carbon for an efficient biological process. At the WWTP, nitrogen removal is the most space and energy consuming activity of the entire treatment process (Beckinghausen et al., 2020).

Water reuse

The regulation on minimum requirements for water reuse (EU) 2020/741 shall be applied from 26 June 2023 on. Of the above mentioned 40 billion m³ of treated urban wastewater, only 1 billion m³ is being reused annually which constitutes a mere 2,5% (Water Reuse Europe, 2020). Spain is one of the largest wastewater producers in Europe, annually producing 5,68 billion m³. However, Spain is also one of the countries in the EU that reuses most of its wastewater (10-13%) (Jodar-Abellan et al., 2019). In tandem, Germany annually produces 3,24 billion m³ of municipal wastewater and Sweden produces 1,18 billion m³ (Statista, 2023a).

In relation to the global market for water reuse solutions, there is a very interesting review of the sector performed in 2017 by the Water Reuse Europe (cf. **Figure 5**), with 787 schemes practicing reuse identified in the EU, distributed across 16 countries. Overall, agricultural reuse remains the most common water reuse application in Europe (with 39% of the schemes) followed by industrial reuse (15%) and reuse for recreational purposes (11%) (Water Reuse Europe, 2020).

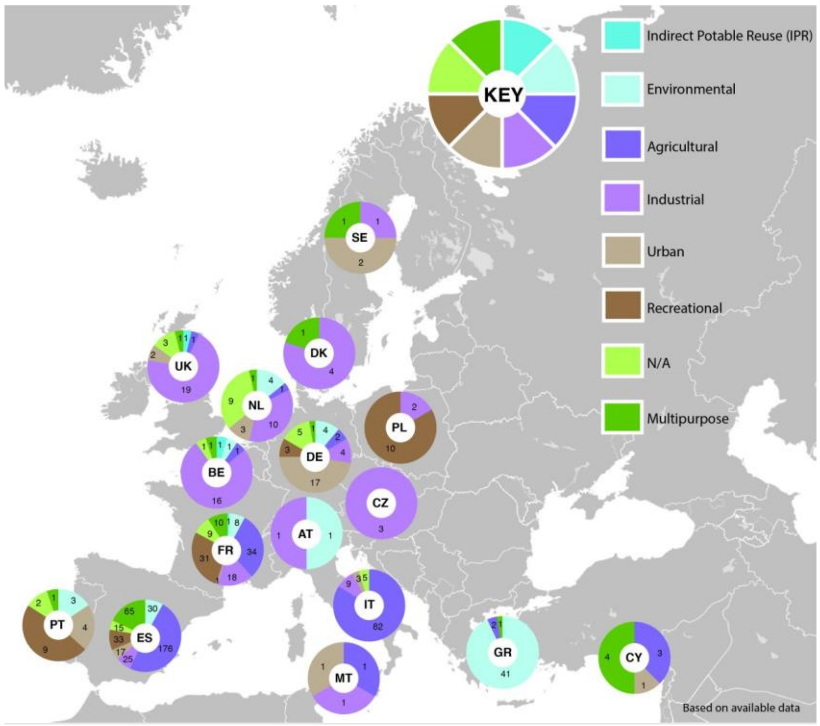


Figure 5. Water reuse schemes per sector in Europe (Water Reuse Europe, 2020)

With the recent implementation of the Water Reuse Regulation, the Member States have been preparing for the application of the new rules, with many of them choosing to integrate the new rules into relevant national law or strategies. Some are also regulating water reuse for applications beyond agricultural irrigation.

Where treated wastewater is reused for irrigation in agriculture, this must be done in accordance with the new rules. However, the Water Reuse Regulation also allows Member States to decide not to practice water reuse in their territory or to limit the water reuse in certain areas. Some Member States, where freshwater resources are abundant and irrigation demand is low, have planned not to allow water reuse for irrigation in their countries. Some Member States have not yet made a final decision, as resource and infrastructure costs still are being evaluated. The **Figure 6** below shows which countries in the EU currently allow water reuse in agriculture.

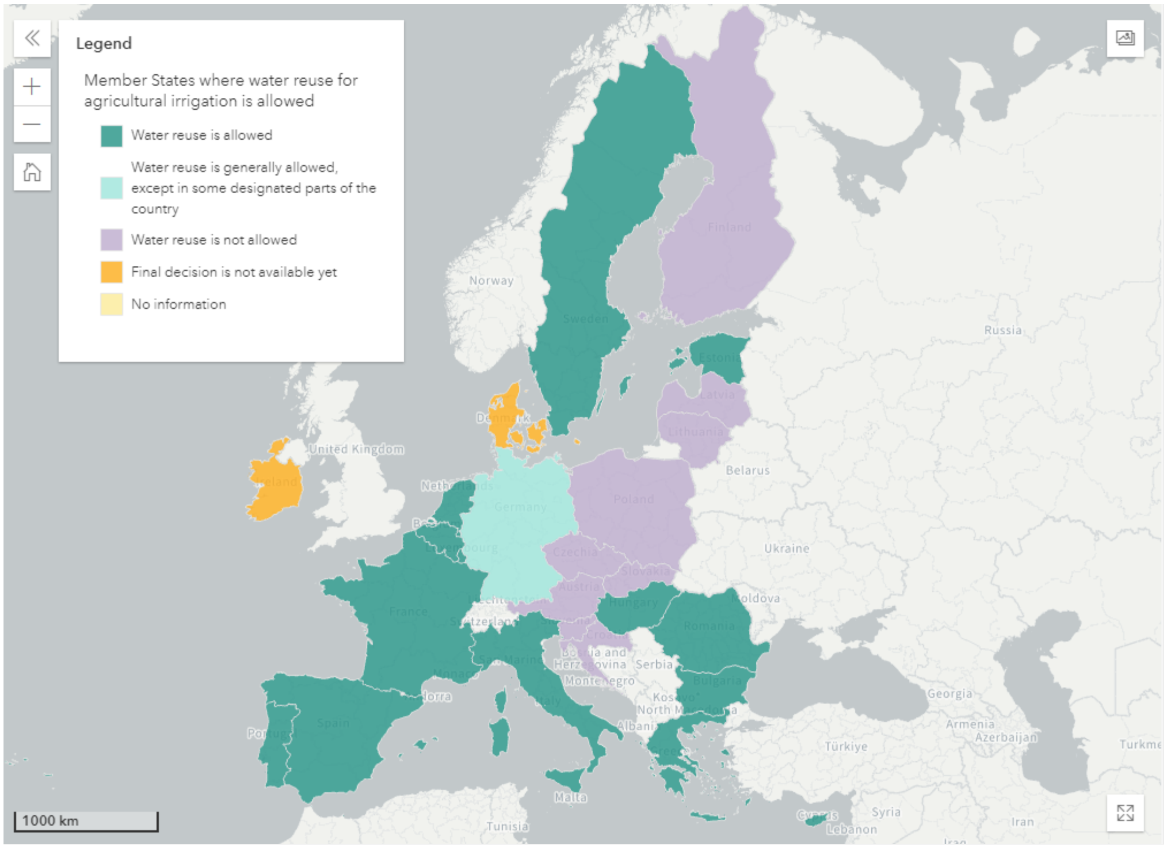


Figure 6. Wastewater reuse allowance for agricultural irrigation in Member States (WISE, 2023).

3 Circular value chain description and maturation status

In this chapter, the maturation of the circular value chains is described per pilot region. The main organisational, technical and legislative achievements and challenges are presented comprehensively and supplemented by the status and first results of the application of bio-based fertilizers in field trails and crop production. The main barriers identified are presented in a table per region and discussed.

Within the three pilot regions, there are four nutrient recycling approaches implemented. In Sweden, a pelletised fertiliser is generated from source separated urine, whilst in Germany the production of a liquid fertiliser is performed in parallel to the production of compost from human solid wastes. In the Spanish pilot region, the approach is based on the reuse of treated municipal wastewater as irrigation water customised to crop nutrient demands (cf. **Figure 7**).

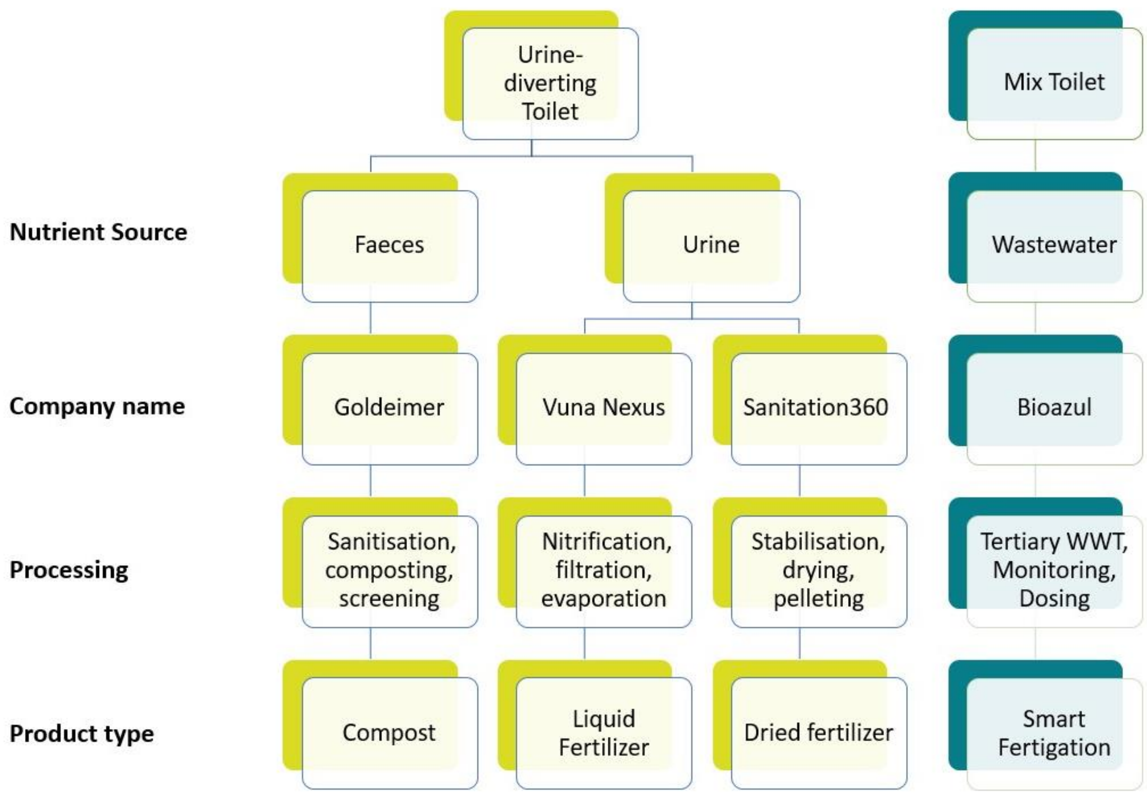


Figure 7. Overview of the four different approaches in P2GreeN.

3.1 Description and maturation of the Swedish circular value chain

In the Swedish Pilot, urine is collected, processed and used to grow barley which is brewed into beer. The technology to produce the solid urine fertiliser was developed at the Swedish University of Agricultural Sciences (SLU) and Sanitation360 (S360), a spin-off from SLU, was started in 2019. To increase urine collection and to close the circular value, Touch Down (TD), local toilet rental company, and Gotlands Bryggeri, local beer brewer, joined to close the circular value chain. The aim in P2GreeN is to collect 150 m^3 of urine by the end of the project to develop a dry fertilizer that can be used with conventional farming equipment. Current operations are located on Gotland, in Uppsala and Malmö and within these next 3 years we plan to scale up urine collection to other areas in Sweden, as well as to neighbouring countries such as Norway. Urine collection can occur from both rural and urban areas and from public or private buildings depending on the installation. A large focus is also on developing methods for the removal of pharmaceuticals and other toxic substances in urine to be able to supply a quality-assured fertilizer. Therefore, tailoring the urine fertilizer we produce to farmers needs is also a major focus.

Maturity of the urinal rental value chain

The Swedish circular value chain starts with the production of a urine stabilizer which consists of a powdery, chemical compound which is placed in the in-situ urine collection tank of urinals and urine diverting toilets. This compound stabilises the urea in the urine and prevents it from turning into ammonia, significantly reducing the occurrence of unattractive odours in and around the toilets as well as mitigating the loss the nitrogen as ammonia gas.

The urinals are supplied by the pilot region partner Touch Down, a local portable toilet service provider. The urine is collected and processed by S360 from urinals placed on the island of Gotland during peak tourist season. The urine is stored in airtight tanks that hold up to one cubic meter each. The urine is then dried, which increases the concentration of nitrogen from 0.6% to 15% and blended with a biological waste product to give it the right consistency for pellets to be made. The circular fertilizer is being evaluated by an independent third-party, Hushållningssällskapet, in field trials comparing dry-urine, liquid urine, commercial fertilizer (NKP: 24-4-5), and no fertilizer. In 2025/2026, the aim is to have produced enough fertilizer to work with subcontracted farmers in large-scale field trials (3-6 ha) with barley on Gotland. **Figure 8** showcases some of the process in photos.

Figure 8. Photos of urine recycling process on Gotland. From the left a) Touch Down urinals rented out on Gotland for events; b) Collected and stabilised urine is processed into pellets with NPK of 15-2-4; c) The urine-based fertilizer is used with conventional

A local brewer and project partner, Gotlands Bryggeri, is using the harvested barley, fertilised with urine, for beer production. To date, there has been three beer tastings (2023) to ensure the quality of grain that is being produced reaches the demand of Gotland's Bryggeri. The aim is that by 2026, Gotland's Bryggeri will produce commercially available beer to close the value chain.

This closed circular value chain will be examined within the P2GreeN project and will be levered as proof of concept to show other food and beverage producers that S360's fertilizer is feasible, enabling a wider range of produce to be fertilized with urine.

The system will be installed and further optimized in a wider context at various locations on Gotland, using Touch Down's existing network and maintenance contracts. This includes public toilets in the city of Visby, public beaches and other new permanent installations. Expanding the production of urine-based fertilizer will enable integration into a circular value chain that can eventually move beyond Gotland and even Sweden. **Figure 9** below gives an overview of the flows of intellectual property, physical good and finances.

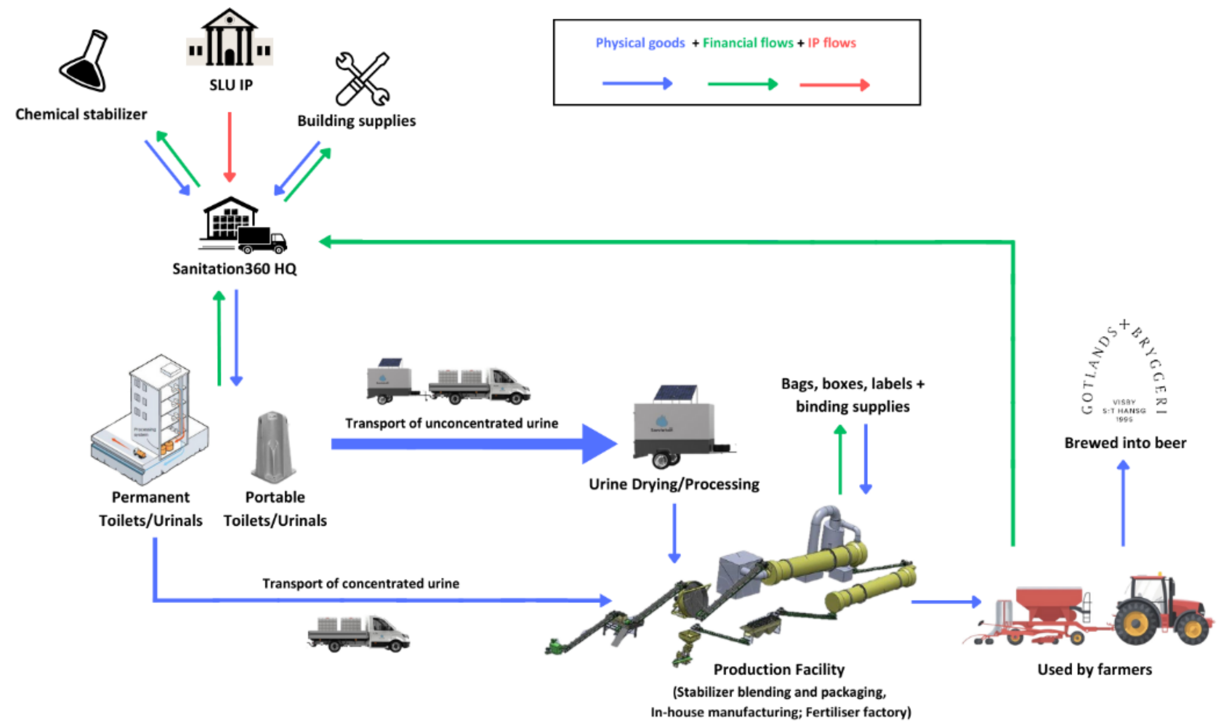


Figure 9. Scheme of the value circle of the Gotland pilot region. Note: The Production Facility is to be built in 2025.

Maturity of the safe urine fertilizer production process

At the start of the P2GreeN project, stabilised urine was being processed at about 60 L per day using primarily solar and wind energy. The limiting factor for increasing the treatment processing rate is access to enough energy. Now, S360 is investigating and building two alternative systems: one that operates with only waste heat from the local cement factory (permission received in November 2023); and a second that recuperates the heat from the exhaust to enable us to reduce the energy demand. Both set-ups will be tested in winter 2024. Concurrently S360 is investigating how best to pelletise the urine fertilizer.

At SLU, several (other funded) projects investigating the removal of micro-pollutants during the drying process are carried out to determine that the cleanest fertilizer can be produced. The experiments are currently at bench-scale; however, existing technologies is being used, and adapted to urine, with the intention to be able to integrate the process before the end of this P2GreeN project. One study that evaluated the inactivation of 75 pharmaceuticals in urine showed that 90% of them were possible to reduce by 55% using UV light in the urine pre-drying (Demissie et al. 2023).

Maturity of field trials

Hushållningssällskapet (Rural Economy and Agricultural Societies, an independent agricultural advisor) is performing the barley field trials on Gotland with the dry urine fertilizer. The field trial includes 4 treatments: urine pellets, commercial fertiliser, liquid urine (unconcentrated) and no fertiliser. The equipment and field set-up are showcased in Figure 10. The farming equipment are replicates of conventional farming equipment, however, narrower so that it's possible to simulate using typically farming equipment without needing very large surface areas. A combi-seed drill is used to apply the fertilizer with the barley together directly into the soil. The width of the fertilized row is 1-2 cm and is placed 5-7 cm deep. The fertilized row is 6 cm from the seed row, like most combi-seed drills. Each replicate width is 1.5 m and 12 m long, and each treatment is replicated 6 times.

Figure 10. Farming equipment and set-up of field trials. From the left a) combi-seed drill where the barley and the urine pellets are buried into the soil 5-7 cm deep; b) visualisation of the 1.5 m wide replicates; and c) combine machinery used to harvest the barley grain**.**

In the 2022 field trial, the urine fertilizer was prilled, but this was too wet and the prills were not uniform. In winter 2023, SLU used a meat grinder to produce the pellets used for the summer 2023 field trials. The process worked; however, it was labour intensive and the quality varied. SLU is now communicating with professional consultants in this field to assist with the production of the pellets for summer 2024 field trials.

The harvest from 2023 was the best thus far with 6 500 kg barley/ha harvested (extrapolated from the 6 replicates which were 1.5 m wide and 12 m long replicates) for both S360 fertilizer and the conventional fertilizer. The results are summarized in **Table 1**. The ideal protein content is between 9.5 and 11.5% for beer production. Higher protein values lead to inefficiencies in the brewing process and to increased foam (head) forming while serving the beer, which is less desirable. The higher protein values from this year's harvest (13%, cf. **Table 2**) are something that SLU, S360 and Gotlands Bryggeri are investigating with barley producers to help lower the concentration in the coming harvests.

Barley Field Trial

2023 Information

Planted: 2023-04-26 in Bro, Gotland Sweden by combi

Harvested: 2023-08-27

Barley Type: Planet

Surface area: 720 m^2 as depicted in the image on the left. The trial was in the middle of barley field seeded by the farmer Lars-Erik Westergren as seen in the image below.

Fertiliser Treatment	N-P-K Content (%)	Mass fertilizer applied (kg/ha)	P supplement (kg/ha)
S360 Fertilizer	15-2-4	567	29
NKP fertilizer	24-4-5	370	0
Fresh urine	0,6-0,07-0,2	14 167	21
Control	0-0-0	0	0

Figure 11. The Swedish Pilot 2023 Field trial information. The image on the left is the schematic of how the treatments were placed in the field as a randomised treatment block design. Note: the frass is from another fertiliser treatment experiment at SLU and the results are not reported here. The table above contains specific details about the fertilisers used. The image of the barley field showcases how the field trial was in the middle of the farmers own field of barley. All barley was irrigated as needed.

Table 2. Field trial results 2023

Fertiliser Type	Fertiliser Mass (applying 85 kg N/ha)	Yield (kg Barley/ha)	Protein (%) (Ideal = 9.5 - 11%)
S360 Fertiliser	598	6 500	13.0
Chemical (NPK)	370	6 500	13.1
Fresh Urine	14 182	5 500	13.6
No Fertiliser	0	4 500	12.0

Challenges with scaling up and lessons learnt in the Swedish pilot

In Sweden, it is a favourable prerequisite that urine is not forbidden as a fertiliser. However, for the technology to scale-up, a new supply and service chain is needed to support this paradigm shift. In looking at what financial incentives there are at each part of the value chain, it can be concluded that in Sweden there is little to no financial incentive at this point (cf.**Table 3**).

Table 3. Identified challenges and barriers of the Swedish pilot region rated by their perceived level: red = higher; orange = medium; and green = lower barrier.

	Tech	Acceptance	Financial Incentive
Collection at source	Systems on the market; Development needed	Low use of urinals; high prize UDDT	None to against
Treatment	In development (TRL 6)	Too many questions and unclear responsibility	Little to none
Reuse	Fertilizer = good; Final product in development	High acceptance with farmers; however, too small volumes	None

The acceptance of recycled nutrients from urine will likely remain relatively low because of the cost of the collection infrastructure, the treatment system and of producing the fertiliser. In addition, there are many uncertainties in terms of accountability for the management and safety of the fertiliser. And finally, for the reuse, farmers have stated that the use of urine as a fertilizer is very welcome, however the current production volumes are too small (Parfitt, 2023). And within this P2GreeN work package (WP 1), the aim is to address the column under technology in order to increase the amount of urine we are able to collect, treat and produce as a fertilizer, whilst other columns are tackled by colleagues from other WPs.

Governance readiness level for the Gotland Business Model

Even though Sweden has been a pioneer in developing resource-recovery sanitation solutions since the 1990s, implementation rates of these systems have been at a standstill for decades (Bengtsson & Tillman, 2004; Söderholm et al., 2023). The reasons for this are multitude, such as broadened sanitary regulations, a lack of acceptance and knowledge of alternative solutions and the fact that the Swedish sanitation system is highly centralized, which means there is a large technological lock-in barrier (Söderholm et al., 2023).

Revaq is the Swedish Water and Sewerage department's own quality insurance system for assuring the sludge quality. Revaq-certified WWTPs treat approximately half of Sweden's municipal wastewater and are built to remove nutrients like nitrogen and phosphorus from the aqueous phase, for phosphorus with a focus on bind it to the sludge (Eurofins, n.d.). Whilst Revaq is a great circular initiative, this certification is not relevant for S360s urine fertilizer as it only covers sludge that is processed at WWTPs.

In addition, the governance framework creates uncertainty for source-separation systems. It arises from the absence of explicit definitions for urine, sludge, and wastewater in regulations, adding a layer of difficulty to their categorization.

Source-separated fractions, including urine, do not neatly align with existing regulations, such as the water and wastewater provision regulation (SFS 2006:412), the sludge regulation (SNFS 1994:2), or the waste management regulations (SFS 1998:808, SFS 1998:899, and SFS 1998:944). Particularly, the regulation restricting the use of plant nutrients in agriculture (SJVFS 2004:62), while explicitly regulating sludge, lacks mention of human urine. (M. Ahlström, personal communication, November 17th, 2023)

Compounding the complexity is the dual regulatory framework based on the location of wastewater generation. Wastewater within public water utilities service areas falls under one set of rules (SFS 2006:412), overseen by water utilities. In contrast, wastewater from private and communal facilities outside these service areas, notably in small rural communities, is subject to a different set of rules (SFS 1998:808, 20 §), with waste utilities taking responsibility. It must be emphasized that if collected outside public water utilities service areas, urine fractions are deemed waste rather than sludge, further contributing to the intricate legal considerations surrounding urine management in Sweden. (M. Ahlström, personal communication, November 17th, 2023)

In practice, urine is allowed for use in conventional farming in Sweden which enables S360 to sell the urine fertilizer to conventional farmers and for them to be able to legally sell their produce. However, it used to be allowed in organic farming as well before Sweden joined the EU in 1994. Joining the EU meant that Sweden had to follow the EU's regulations for organic farming, which does not permit urine to be used as a fertilizer. In Sweden there is another common certification for sustainable farming called KRAV, which could become a potential certification for urine. However, in order to be a KRAV certified farmer in Sweden, the farmer first has to be certified EU-organic. These two certifications therefore go hand in hand and urine fertilizer is not mentioned as an option in KRAV's regulation under section 12.3 "fertilizers and soil improvement". This prohibits S360s urine fertilizer from being both EU-organic and/or KRAV certified.

Organic/KRAV-certified farming constitutes about 20% of farmed land in Sweden and out of the farmers S360 has talked to, the organic/KRAV farmers have also been those who've showed the greatest interest in using urine fertilizer, as this would be one of the only fertilizers with directly available plan nutrients, not requiring mineralisation of organic material to access the plant nutrients. Meaning the European legislative framework is a huge market inhibitor for the produce.

The national SPCR 178 certification is currently the only applicable fertilizer certification for source-separated urine. It might go out of commission due to the relatively high costs of obtaining and maintaining the certification. Furthermore, the circular and environmental benefits of choosing urine need to be added to the SPCR178 certification for S360 to see a value in obtaining it. On the legislation side SJVFS 2004:62 regulate the use of fertilizer on agricultural land. All organic fertilizers of biological origin are allowed for use in Swedish agriculture. The restrictions are on the amount applied, assuring not to over-fertilise, and related to wastewater products not to add high levels of heavy metals.

3.2 Description and maturation of the Hamburg-Hanover circular value chain

The circular value chain of the pilot region Hamburg-Hanover consists of four partners and is based on an interregional urban-rural transaction and divisional treatment of solids and liquid human sanitary waste.

Ecovillage Hannover (EVH) is planning to collect approximately 100 m³/yr urine from 350 tenants using 100 urine diverting flush toilets (UDFT). The separated yellow water (urine + flushing water) is drained via a dedicated network serving an area of 2 ha. The urine will be processed at the premises of EVH in a central facility using the Aurin® system provided by VunaNexus (VN), who will also take care of necessary adjustments, operation and maintenance of the system. The Aurin® fertilizer will be marketed by VN. The system's treatment capacity is designed with 500 l/d capacities so to give the opportunity to Goldeimer to add urine resources from their serviced toilets.

Besides urine, Goldeimer (GE) will collect mainly dry toilet contents from festivals, allotment gardens and off-grid nature tourism destinations. A thermophilic container-based composting plant for faeces will be set up, further automating the technology developed by GE's network partner Finizio (TRL 5) and operated by GE on the Vagtshoff farm in lower saxony near Hamburg. The Vagtshoff farm provides industrial waste heat and biochar for the treatment facility, as well as the agricultural fields for fertilizer application.

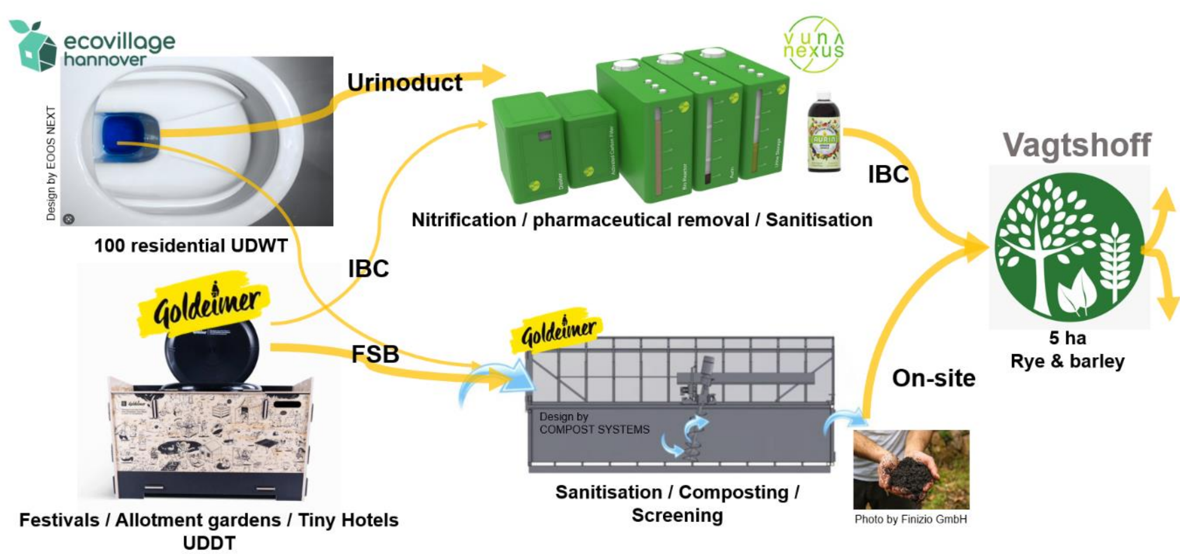


Figure 12. Scheme of the value circle of the Hamburg-Hanover pilot region.

Figure 13. The bio-based fertilizer products produced in the Pilot Region Hamburg-Hanover are Aurin®, which is an authorised fertilising product in Austria, Switzerland, Lichtenstein (left photo by Vuna GmbH – vuna.ch) and (right) compost made from solid human waste from dry toilets (right photo by Finizio GmbH – finizio.de).

Maturity of EVH premises and VunaNexus treatment installations

With the beginning of the P2GreeN project, the planning of each house of the 15 houses of the first construction sector had been finished, including the new toilet types, the additional piping and specific venting and maintenance requirements. The planning for the yellow water network as well as the flushing water distribution (from treated greywater), has been developed from a level of basic determination to a design planning status. Knowledge exchange with the St. Vincent de Paul project engineers from Paris, where the network has already been implemented in 2021, have been initialised. Due to the following reasons, it has not been matured further from this point on.

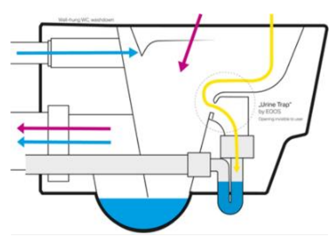


Figure 14. Images and schemes of the urine diverting flush toilet (above, courtesy of EOOS NEXT) and the urine treatment technology provided by project partner VunaNexus (below).

The financing concept for the EVH construction has been stressed multiple times, leading to severe and ongoing delays of the readily planned construction. Whereas the first unforeseen event occurred overnight 2022, when in January the KfW40+ programme was stopped by the new minister of economics, the second event was a protracted one: The NBank started examining the evh case only after an alternative loan contract could be closed with KfW in April 2022, and subsequently it took NBank one year to check very thoroughly on the documents and conditions of the planned endeavour.

When the NBank decision was finally received in April 2023, the financial and risk framework had changed significantly compared to the situation before April 2022. This development led to the decision of one of the three banks, forming the bank consortia to manage KfW loans, to withdraw their engagement.

The complexity of the overall financial systems with multiple equity and outside capital elements is making the current negotiations with new partners to fill the current gap of approximately 2 Mio. € very challenging. P2GreeN partners CBS and Triodos have analysed the situation and consulted evh.

The development of 160 flats for approx. 350 people is ready to be executed from all other aspects: The property plot has been purchased, the planning has been completed, the building permissions for the 15 planned houses have been granted.

A first demonstration building has been built (‘modulpilot'), where the execution has been successfully taken place on the building scale level. Questions of the piping (dimensions, angles, shaft allocation), maintenance access have been tackled and as well as the capacity building of the installation company has taken place based on a newly developed yellowwater planning and installation guideline.

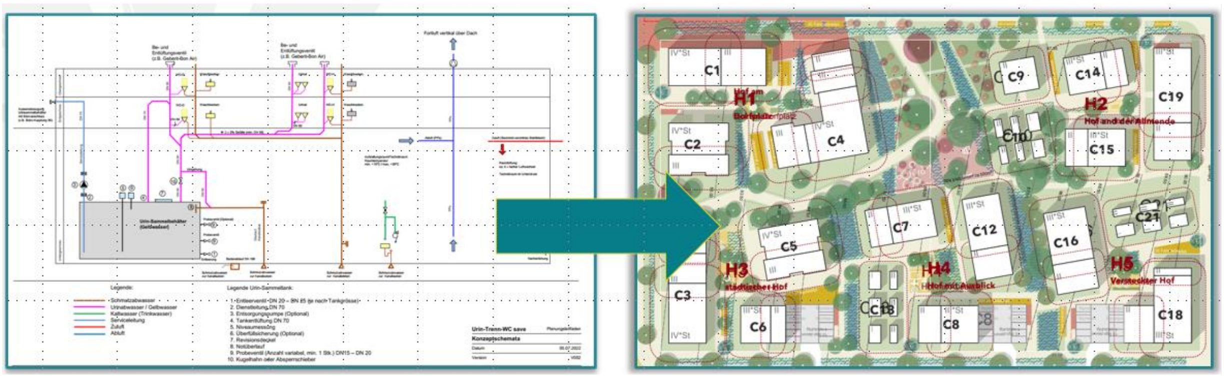


Figure 15. Upscaling approach of evh from building scale to neighborhood scale on their 2 ha premises hosting 15 houses and 350 tenants.

Maturity of Vagtshoff premises and Goldeimer treatment installations
At the Vagtshoff farm in the municipality Hanstedt, GE has been operating its material and logistics hub since the year 2015. GE's value proposition is to make a walk to the loo a fun experience on public events, to educate people on resource-oriented sanitation and the global sanitation crisis (SDG 6). Since 2013 they are renting out their 80 mobile toilets mainly to music festivals.

Figure 16. Event toilets as provided by project partner Goldeimer and bins used for solid waste logistics.

But until today, GE was not able to comply with its intention to close the value chain from excretion to nutrition from their own capabilities. Collected faeces have been treated at Germany's so far only recycling premise for human excreta collected without water in Eberswalde, operated by the network partner Finizio. The process consists of three treatment steps:

1. Sanitisation of dry toilet contents by thermophilic composting
2. De- & Recomposition of organic matter by oxygen-controlled composting
3. Extraneous material extraction by screening

Based on the experiences of Finizio (TRL 5), the GE composting system aims at improving economic viability with the introduction of a new technology for the oxygen-controlled composting (Step 2). The highly automated and so called "earthflow" composting system is displacing Finizios labour intense heap process, whereas the first step of the process is adapted without substantial modifications. Therewith, both steps 1 and 2 are container-based.

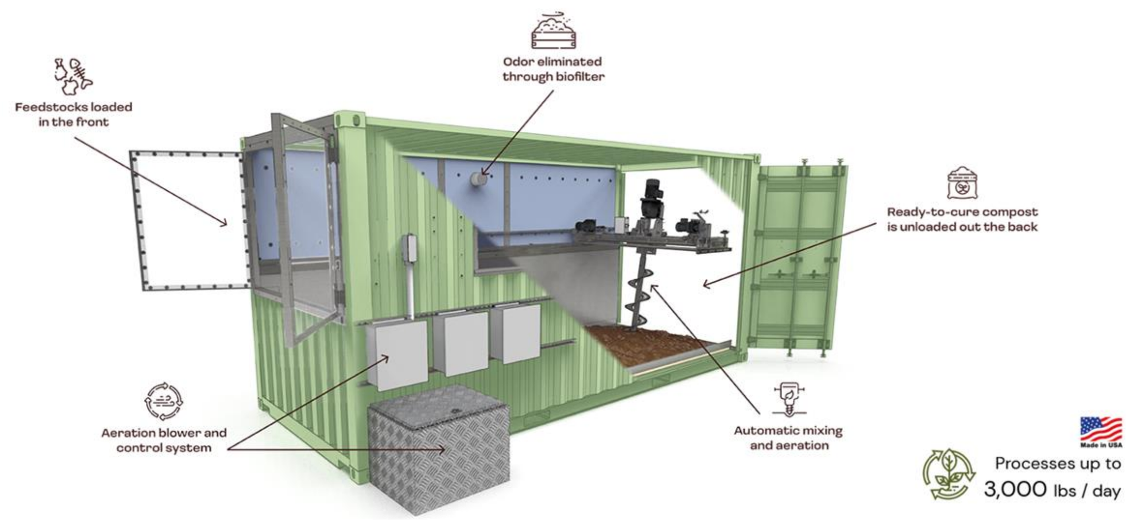


Figure 17. 3-D image of the "Earthflow" container for highly automated and oxygen-controlled faeces composting at Vagtshoff (courtesy of Green Mountain Technologies)

The machinery has been purchased and (dry) commissioned at the Vagtshoff. The approval planning is in progress with the local authorities. First exploratory talks with the related authorities (construction, water, emissions, nature conservation) have taken place in parallel with the approval process for the field trials (cf. 4.2.2.) and matured ever since then (cf. 4.2.4.).

Figure 18. Top – Container system for the sanitisation of dry toilet contents by thermophilic composting (step 1). Bottom: “Earthflow” container system for De- & Recomposition of organic waste by oxygen-controlled composting (step 2)

With the support of LEADER fundings, Goldeimers sister company PyCCS GmbH has commissioned a pyrolysis plant at the Vagtshoff. The goal is to produce biochar as a) litter supplement for the operation of dry toilets (“dry flush” to cover faeces and adsorb odor) and b) to improve the physico-chemical properties of the faecal compost receiving soils.

Maturity of field trials at Vagtshoff

Both faecal compost (~40 t DM/yr) and Aurin® fertilisers are planned to be used in a supplementary way to grow agricultural crops. The intended test area is located in the municipality Hanstedt on the coordinates 53 ° 13,52.0 "N 10 00'36.9" E in a water protection zone. The sandy soils have been extensively used in recent years without adding fertilizers. A total area of 6 ha is required for the field test (Fig. 1). The recycling fertilizers faecal compost and Aurin® are to be applied on an area of 4.56 ha. This roughly corresponds to the area that is needed in order to be able to spend the quantities of recycling fertilizers (faecal compost + Aurin®) produced during the project duration. The planned output of faecal compost is well below the upper limit for compost fertilizers (30 t DM/ha in three years) defined in the BioAbfV § 6. The limits of the output quantities of faecal compost and Aurin® are therefore largely resulting from the N and P requirements of the plants. The rest of the area is required for the comparison treatments (0.48 ha) and a not fertilized edge strip of at least 9 m to the next blow (0.96 ha).

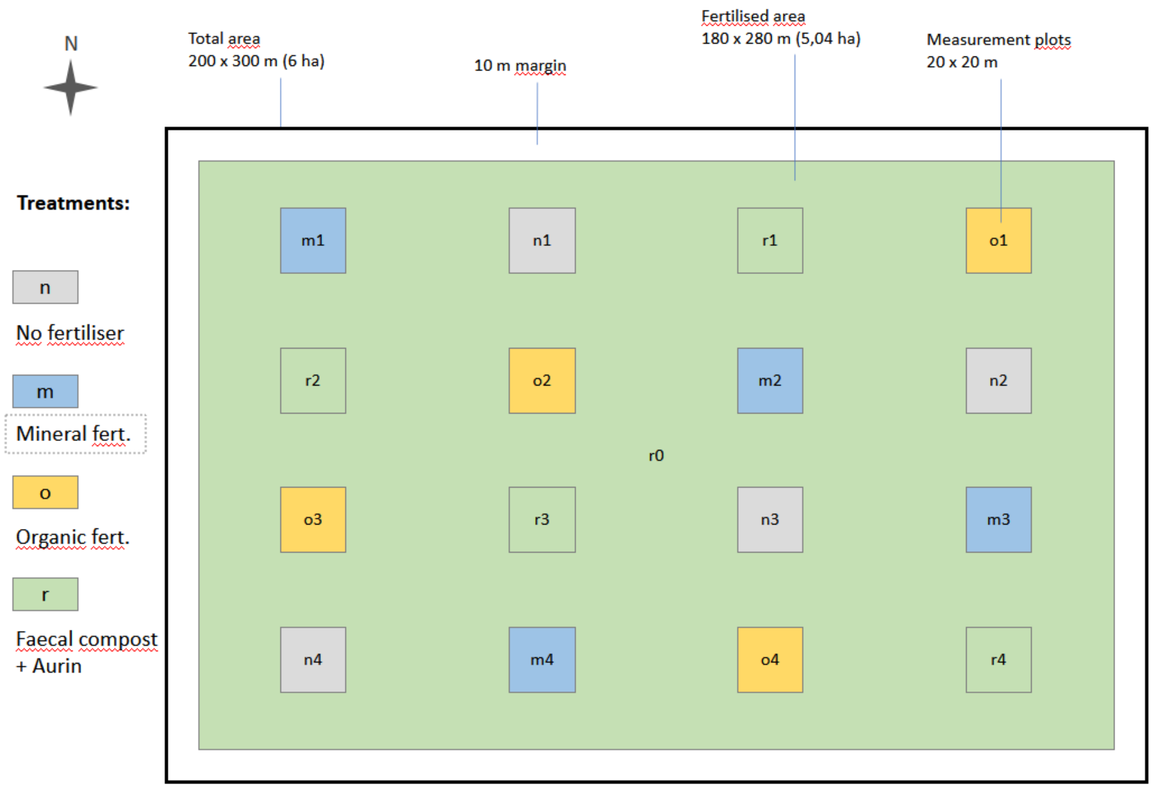


Figure 19. Authorised structure of the field trial near Hamburg with the arrangement of the measuring plots for various fertilizer treatments in a "Latin Square Design".

The concept has been registered and acknowledged based on DüMV §4 4/5 by the federal fertilizer authority, with the exclusion of realising the r0 area (4.56 ha). As this limitation is missing a comprehensive justification from the authority, the partners of the pilot region are planning to claim the full scope subsequently.

Challenges with scaling up and lessons learnt in the German pilot

The main challenges for the German pilot region originate in the legislative framework (cf. 3.2.5). The intersectoral, unclear legislation and the locally diverting and arbitrary decision making have impacts on the technical plannings. Authorities have the duty to avoid risk for people, animals and the environment, and where the risk has not been clarified by law or technical directives, the legal and administrative requirements to safeguard all risk prevention measures are often system overarching whilst public administration is often limited to their pre-determined scope of singular (and linear) responsibility. Two examples shall provide more specific details on the described situation.

Regarding the yellowwater network for evh, the interaction with the local authority (Stadtentwässerung Hannover) showed that the requirements for domestic discharge waters (SEH, 2016) limit the interaction of the yellow water and the sewer system. For the potential occurrence of yellow water system overflow, the sewer system offers capacities. But the high nutrient content of yellow water is well above the existing parameter thresholds for discharge and therefore has a strong impact on the technical requirements as well as the effort to monitor the system. To cope with this challenge technically, an additional tank to dilute yellow water overflow with greywater can be foreseen, but naturally has a negative economic impact. It remains to be clarified if more cost-effective governance solutions can be achieved.

Barriers for the yellow water collection also exist based on the currently higher prices of the innovative user interfaces (UDFT) and the delayed planning and building process for the yellow water area network. Regarding the treatment, the technology itself is ready to be demonstrated in operational environment, but its price and space invested results in additional costs for tenants currently. As the product Aurin cannot yet be marketed locally, hence the nutrient reclamation is hindered and the financial incentive for the implementation of the closed value chain is not given. The challenges and barriers for faeces valuation in the German pilot are aggregated in **Table 4**.

Table 4. Identified challenges and barriers for urine valuation in the German pilot region rated by their perceived level: red = higher; orange = medium; and green = lower barrier.

	Tech	Acceptance	Financial Incentive
Collection at source	Areal planning & Realisation overdue	Great will by associates to use; permit pending	Additional cost for WC and add. Piping; water savings
Treatment	VunaNexus integration planning done, sensitive process managable	multiple use of facility; footprint; cost	Treatment cost higher than deposit to sewer
Reuse	Questions of applicability with farming operations	General openess by farmers, but illegal	Price of mineral fertilizers lower; no benefit from eco-engagement

In terms of the faecal composting, the water draining from the grounds used as material hub is believed to be considered contaminated and harmful for humans and environment by the local authorities and as such must be captured, stored and eventually deposited in a controlled manner. This requires advanced constructive works and spendings on a drainage system, logistics and deposition fees. The additional costs originating from this requirement might be a crucial barrier for follower farmers to take up this business opportunity.

In terms of the faecal composting, the subjective barriers aggregated in **Table 5** turn out to be lower than for urine valuation. Whilst the technological readiness level and the acceptance in terms of material collection and treatment is not recognized as a barrier, the financial incentives and the feasibility of the product application and thereby the valuation of the closed faeces value chain is hindered by the current legislative framework.

Table 5. Identified challenges and barriers for faeces valuation in the German pilot region rated by their perceived level: red = higher; orange = medium; and green = lower barrier.

	Tech	Acceptance	Financial Incentive
Collection at source	Operated; amounts sufficient	Public awareness rising	Eco-solution at higher cost than conventional
Treatment	Technology ready, optimisation tbd	Similar to other farmers practices	Treatment cost higher than conv. composting
Reuse	Only within research framework	General openess by farmers, but illegal	no incentive for regenerative agriculture

Governance readiness level of the Hamburg-Hanover value chain

In Germany, the P2GreeN project encounters a plethora of legislative barriers. Challenges span from waste transformation compliance to setting up decentralized systems. Legal complexities impact yellow water recycling, faecal composting, and field trials. However, potential opportunities arise from aspired federal living-lab laws.

The main entry barriers for the P2GreeN products are to comply legally and to assure its harmlessness. But also on the way of transformation from waste to resource qualified to become a produce, various barriers exist in different sectors and laws. Whereas yellow water collected from less than 50.000 PE appears to be qualified for N- and P-recycling as sewage sludge in accordance with the CMC regulation, this is not the case for contents of dry toilets as they are confronted with barriers in the municipal statutes based on the Water Household Act (WHG §55/56), the Circular Economy Act (BioAbfV §3) and the Fertilizer Act (DüMV Annex II, Table 7). There is also no guidance for the waste key application to sanitary waste from dry toilets (91/689/EEC; AVV). This fundamentally counteracts the principle of the waste hierarchy – Prevent, Reuse, Recycle, Recover, Dispose - of the federal Circular Economy Act (KrWG § 6 (1)).

The source separation and local treatment of yellow water was not yet authorised for ecovillage hannover. Due to the above-mentioned delays, the engineering of the decentral wastewater system of EVH has been set on hold. Nevertheless, in terms of yellow water, insights into the Water Household Act and its subordinated rules have been made multiple (cf. above). The overall path pursued technologically and legislatively in Germany for sanitary waste is strictly encompassing sanitary waste as wastewater. The renewed sewage sludge regulation (AbfKlärV 2017) and its Governance Framework is streamlining stakeholders to the mono-incineration of sewage sludge with the aim of P-reclamation from ashes. The soil-regenerating- and N-potentials of sanitary waste are compromised on this pathway.

Regarding the set-up of the faecal matter composting, first exploratory talks between the planning engineering office and the related authorities (construction, water, emissions) have taken place. It turned out that BauGB §35 (1) sentence 1 can serve as the building law basis and is resulting in lower barriers in the approval process: "Building outdoors is only permitted if public concerns do not stand in the way of public development and if it serves an agricultural or forestry operation and only takes up a subordinate part of the operating area". It can be assumed that the area falls under the AwSV and the TRwS 792 / JGS rules with less requirements and evidence obligations then for clients outside agronomy. This agricultural privilege has been identified as a high-potential entry point in the development of business models for farmers.

Currently there is a stalemate regarding the accountability for the drainage water from the faeces composting facility: Agricultural wastewater may not be fed into the public wastewater disposal system of the district or municipality. At the same time, the wastewater produced during the composting of human excreta may not be used for regular agricultural purposes as liquid manure without special permission from the fertilizer authorities. The next step will be to seek clarification with both public authorities once the planned constructions are permitted.

The field trials can only be legally performed based on the privilege of scientific projects and on the experimental paragraph of the German fertilizer Act (DüMV §4 4/5). The treatment of the sanitary waste is lacking existing jurisprudence, as Human excretions are defined out of the ordinance for the treatment of organic waste (BioAbfV §3).

It has to be highlighted, that the fact that the field trial area is located in a water protection area did not play a role in the registration process. The field trials are also acknowledged on plots certified for organic agriculture, but unfortunately it results in the loss of this status (and the related subsidies of approx. 450 €/ha*yr) since the material is not mentioned as a Component Material Categories (CMC) of the Fertilising Products Regulation (FPR).

In-depth studies on the option of achieving CE label for the studied bio-based fertilisers from human excrementa are provided in deliverable D3.7 Scoping review describing the status of the legislative framework.

The only national framework that is promising to open new opportunities on this endeavour is a new living-lab law (Reallabore-Gesetz), which is currently under development in the Ministry of Economy.

3.3 Description and maturation of the Spanish circular value chain

The Spanish pilot is composed of five project partners, namely: AXARAGUA as the public operator of the Algarrobo municipal wastewater treatment plant, BIOAZUL as technology provider for wastewater reclamation, the farmers cooperative TROPS for the crop management and as technical advisor for fertigation, AgriSmart Data as software developer of the Smart Fertigation Tool and the water research centre CETAQUA as scientific partner for the analysis of the collected data.

The circular value chain of the Axarquía pilot region starts with the collection of sewage from the municipality of Algarrobo and nearby municipalities. Municipal wastewater is collected and transported to the Municipal Wastewater Treatment Plant (WWTP) of Algarrobo (coordinates: 36°45'13.0"N, 4°02'55.8"W). The WWTP receives an average influent of 2.150 m^3/day (i.e. 12.247 p.e.), with maximum capacity of 24.000 p.e.. It is operated and maintained by AXARAGUA, a public company created by the "Association of Municipalities of the Costa del Sol-Axarquía" to directly manage the drinking water and wastewater treatment of the joint municipalities. Besides Algarrobo, AXARAGUA carries out the wastewater treatment in the municipalities of Vélez-Málaga, Rincón de la Victoria, Torrox and Benamocarra.

The raw wastewater from the sewer system, once it enters the WWTP, goes through a series of primary and secondary filtration, sedimentation and flocculation procedures. The secondary treatment must offer optimal treatment performance, complying with the provisions of the European Directive 91/271/EEC. After the secondary treatment, the outflow is discharged entirely into the sea through an underwater outfall. As there is no denitrification process in place, the amount of nitrogen released from the Algarrobo WWTP to the mediterranean sea is relatively high (28,8 tN/year).

In the Spanish pilot region, a tertiary treatment (i.e., Water Reclamation Plant) is replacing the before existing RichWater® system installed in the proximity of the WWTP by BIOAZUL. The water reclamation plant is operating and providing reclaimed water in the scope of P2GreeN since Month 3 (February 2023). An approximate volume of 16 m^3/day, tailored to suit the crops needs, of secondary effluent from the WWTP outlet is transported through a pump that feeds the tertiary system. After the tertiary treatment, the effluent is classified as reclaimed water, a nutrient-rich effluent with agronomic value. Reclaimed water is then transported through a pipeline and stored in a deposit tank, part of the mixing unit. From the deposit tank, reclaimed water will be used to fertigate the crops and, if needed, it will be supplemented by mineral fertilizers or diluted with local water, under the control of the Smart Fertigation Tool (SFT). The Water Reclamation Plant is operated by BIOAZUL the coordinator of the pilot region.

Reclaimed water will be used to fertigate avocado and mango crops planted outdoors in the test site. The crops are cultivated and managed by the pilot region partner TROPS, a cooperative of around 3,000 farmers in the region, but also technical and agronomic advisor on crop management. Based on the crop demands, in terms of irrigation and nutrients, the fertigation will be adjusted to meet the requirements of the trees.

In this sense, the Smart Fertigation Tool will provide information on the level of main nutrients and elements in the soil that most affect the development of crops. The tool allows the connection of sensors and transducers installed in the soil that will provide information on multiple parameters and can also manage irrigation and fertilisation automatically, based on the actual levels in the roots of the plants. The tool will also incorporate data from water sensors installed in the deposit tank with reclaimed water. Additionally, the tool will allow the remote control over the dosage of fertilizers and mixture of water sources automatically, by means of a Decision Support System (DSS) integrated. The Smart Fertigation Tool will indicate whether additional nutrients are necessary in the reclaimed water, incorporating mineral fertilizers, but also if there is a need to dilute the nutrient-rich effluent with local water (mainly groundwater). This smart fertigation prevents from overaching nutrient application and thereby mitigates the emission of polluting leachates into water bodies (N- and P-emissions to surface and groundwater). The SFT, will be developed by the partner AgriSmart Data, the software developer.

The agroecological and environmental impact assessment, as well as the validation of the data collected in the pilot (including analysis of local water, reclaimed water, soil, etc.) will be carried out by CETAQUA, a water research centre, in collaboration with partners from Work Package 2.

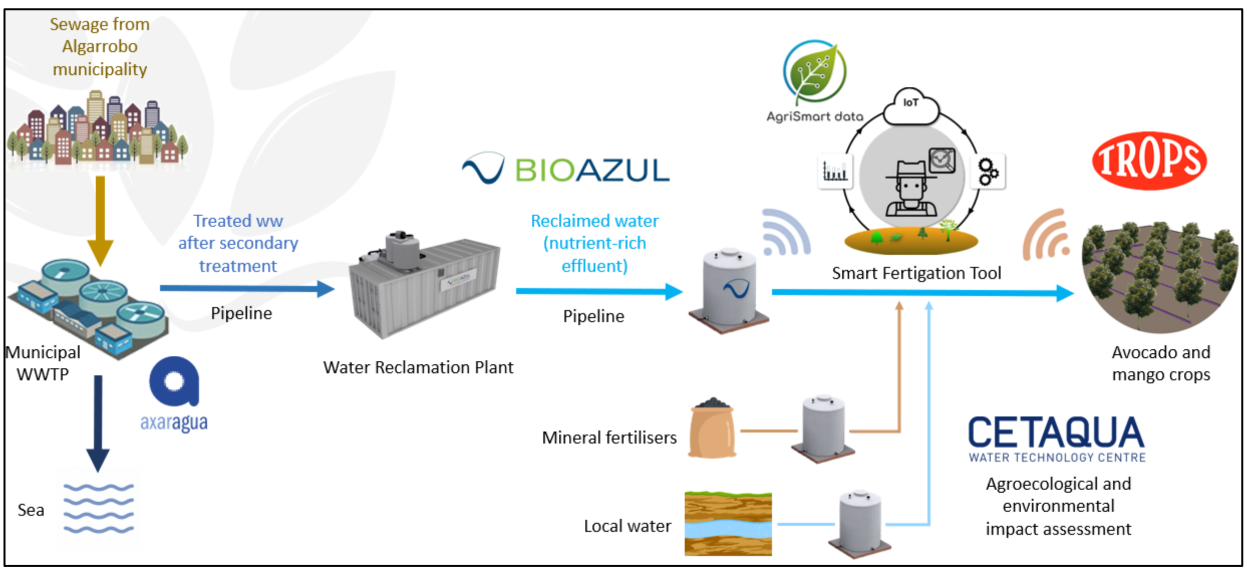


Figure 20. Scheme of the value circle of the Axarquía pilot region.

Maturity of water reclamation

The Water Reclamation Plant providing the tertiary treatment consist of three stages:

- Discs filtration
- Ozone disinfection
- Maintenance disinfection

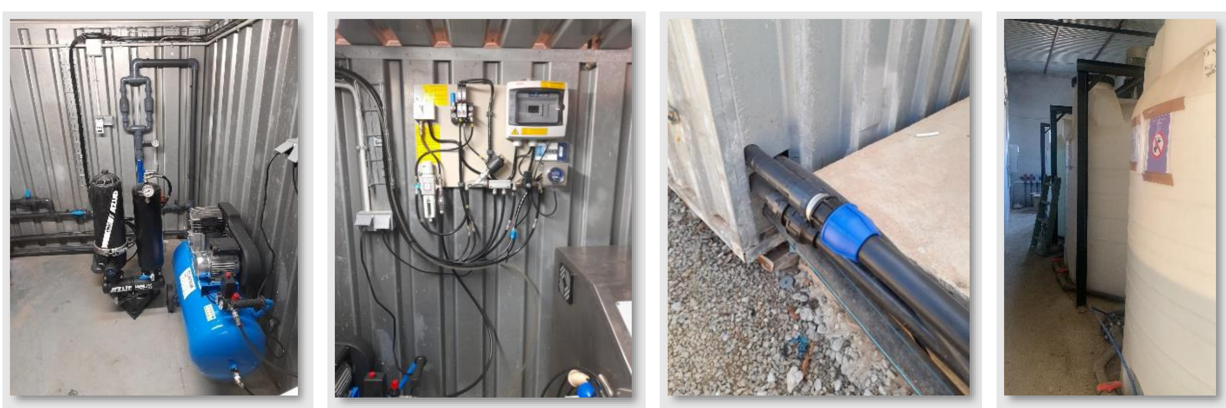
The treatment and production capacity of the Water Reclamation Plant is around 3,000 litres per hour of reclaimed water. The plant is currently running and operated 5.5 hours per day, meaning a potential daily production of up to 16.500 litres per day (16 m³/d of reclaimed water).

The tertiary filtration treatment aims to reduce the content of suspended solids and organic matter, guaranteeing the retention of harmful microorganisms and prepare the water to subsequently apply a disinfection treatment, achieving a suspended solids reduction of up to 80%.

Among the different existing technologies, the installation of a manually cleaned ring filter has been chosen, due to the low flow rate to be treated and the good performance it offers in the long-term, its smaller occupation surface and its lower operation and maintenance costs, simplifying these tasks.

These lower operation and maintenance costs are due to the fact that disc filters have a limited number of ducts, without air requirements for cleaning, with great simplicity of the control systems. They present an excellent response to increases in load. The degree of filtration to be used is set at 100 μm (100 microns).

Once the pressure set on the pressure switch is reached, the filter cleaning protocol will be activated. In our case the filter discs are cleaned manually, but automated backwash installations are also available. Once the washing process is completed, the hydrostatic pressure resistance is decreased, and the equipment filter performance is restored.



Figures 21. Discs filtration towers, control panel, pipeline, storage tanks and mixing unit.

In relation to the subsequent disinfection stage, the objective here is the destruction of pathogenic microorganisms through ozone disinfection, it is automated and requested to comply with the EU Regulation 2020/741 on water reuse. In addition, as the pilot includes the use of storage and regulation tanks, it is necessary to include a chlorination system (with NaClO dosage) to maintain the reclaimed water properties and avoid contamination and proliferation of algae and pathogenic organisms. A control of the free residual chlorine in the effluent will be carried out and action levels will be established according to this control of free residual chlorine. In this way, the necessary dose will be regulated to maintain its quality until the point of delivery for fertigation.

At this point, the high agronomic value of reclaimed water (produced by the Water Reclamation Plant) as a fertilizer in agriculture is recognised, with current and preliminary average values of 30 mg N / l, 5.84 mg P / l and 37.1 mg K / l. In **Figure 22**, the agronomic value of reclaimed water is compared to the local water currently used in the test site – which corresponds mainly to groundwater. In a later stage of P2GreeN, we will be able to compare the NPK content of reclaimed and local water, with the final effluent adjusted by the Smart Irrigation Tool, containing the optimal amount of NPK, based on the crop needs.

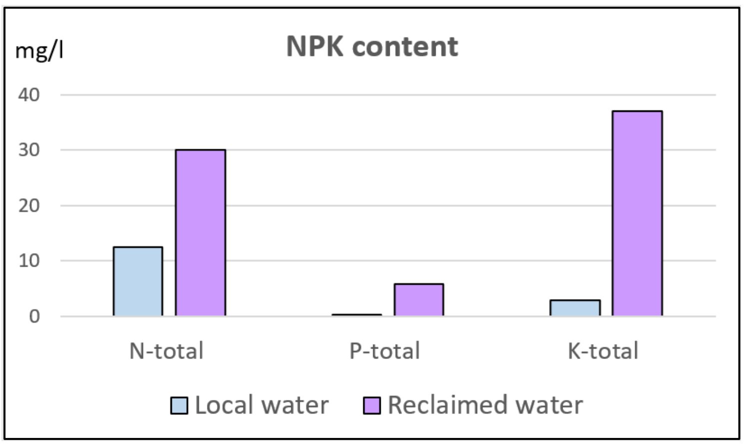


Figure 22. Comparison of nitrogen, phosphorus and potassium content between local water and reclaimed water.

Maturity of field trials

For the field trials, a wide range of renovation and adaptation works were performed in the test site at the beginning of the P2GreeN project. This allowed the preparation and eventual use of two separated plots dedicated to avocado and mango crops. Renovation works conducted include the removal of old greenhouse, assembling of new greenhouse, digging and exchange of soil, preparation of ridges, irrigation pipelines, etc. (cf. **Figure 23**).

Figure 23. Test site construction and adaptation works.

According to the experimental design and agronomic study, 60 avocado trees (Hass variety) and 60 mango trees (Osteen variety) were planted on an area of approximately 850 m^2.

In general, avocado crops are quite demanding for nitrogen in order to achieve an adequate growth and development of the plants, unlike mango trees, for which nitrogen is not so critical. In relation to phosphorus, this nutrient is usually not applied to avocado nor mango crops, unless there would be a very specific deficiency. With regards to potassium, both crops are quite demanding, as it is a key nutrient to convey sugar to the fruit – resulting in larger and vigorous fruits. Another relevant parameter to be considered in the field trials is the electrical conductivity in the water used for irrigation. Mango trees are more tolerant than avocado trees. In fact, mango trees can tolerate up to 2,000 – 2,500 µS/cm, whereas avocado trees are more sensitive and show negative effects with EC of 1,500 µS/cm and above.

For the development and calibration of the Smart Fertigation Tool, and also to evaluate the agronomic potential of reclaimed water, three different fertigation treatments (T1, T2 and T3) are considered in the comparative analysis (cf. **Figure 24**).

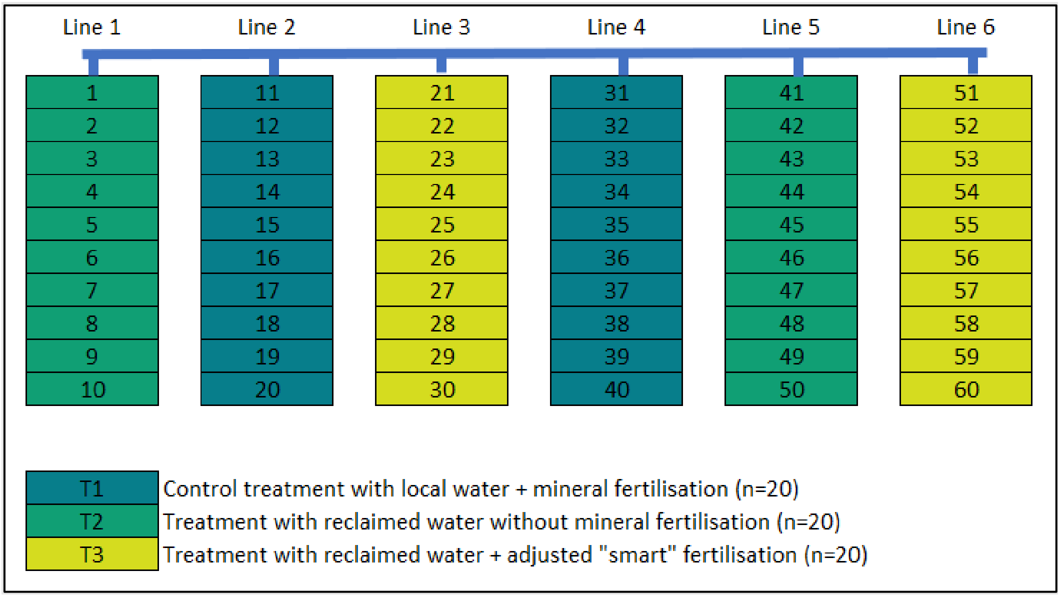


Figure 24. Scheme of fertigation treatments applied in avocado and mango trees.

The scheme is replicated in both avocado and mango plots. Therefore, each of the three treatments is applied to 20 avocado trees and 20 mango trees.

- T1 – Control treatment using local water and mineral fertilisation (n=20). This treatment represented common practice in the region.
- T2 – Treatment with reclaimed water, without mineral fertilisation (n=20). This treatment provides information on the effect of reclaimed water on crops and how far agronomic needs of crops are met without use of additional mineral fertilizers.
- T3 – Treatment with reclaimed water applying the Smart Fertigation Tool currently under development (n=20).

Figure 25. Avocado and mango plots.

The following scheme represents the solution process and establishment of the test site, comparing local common practice of fertigation (T1) in agriculture against the P2GreeN approach (T3).

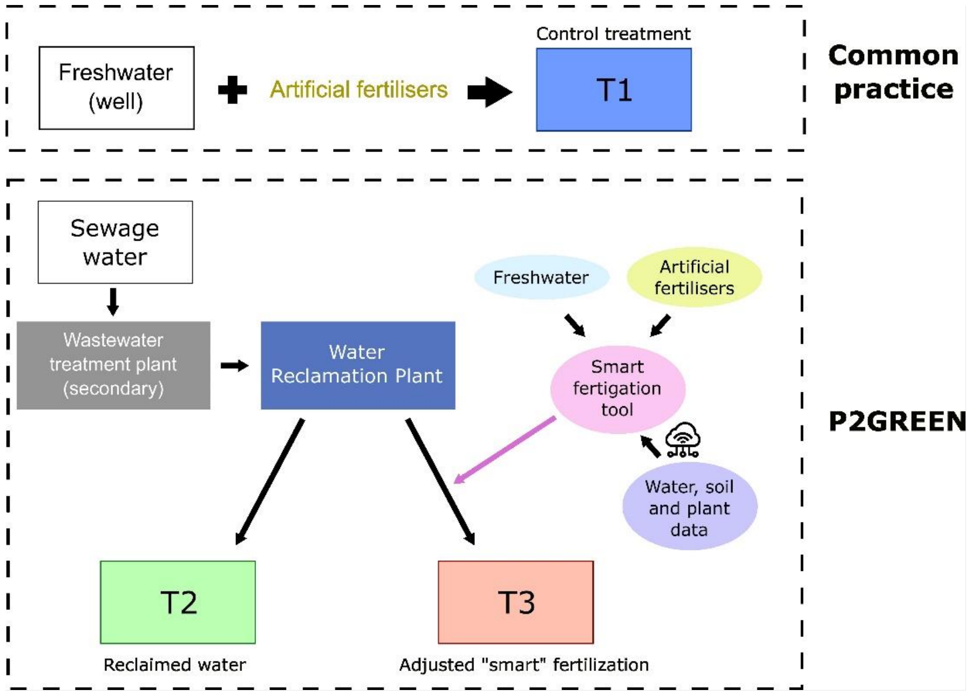


Figure 26. Scheme of experimental site and solution process.

Maturity of Smart Fertigation Tool

The main goal is to develop a digital tool that initially provides information on the levels of the main nutrients and elements in the soil that most affect the growth of plants and in a second phase that will manage to control the dosage of fertilizers or mixture of water sources automatically.

To do this, the iTelemeter V3 equipment will allow the connection of sensors and transducers that provide information on multiple parameters and can also manage irrigation and fertilization automatically, based on the actual levels in the roots of the plants.

To achieve the objective, we face the challenge of testing and developing sensors that will allow us to read the necessary parameters, which are:

- Tensiometric measurement: current physical force of water retention in the soil.
- Volumetric measurement: the percentage of water in a given amount of soil.
- Environmental and root temperature at different depths.
- Electrical conductivity (EC) of the soil at different depths.
- pH of the soil in roots at different depths.
- NPK concentrations in soil at different depths.

The information on the different parameters will be displayed in real time on any computer or phone device with internet access.

iTelemeter is an IoT (Internet of Things) solution that continuously analyses up to 24 parameters per iTelemeter device and acts based on the algorithms that are programmed and at the same time puts all the information on servers for visualization and storage.

In relation to irrigation management, it analyses measurement variables using digital tensiometers at different depths (20 cm, 60 cm and 90 cm) and with automatic operation it executes the irrigation processes in a very precise way - according to the real needs of the trees. These very precise irrigation episodes allow controlling the depth of water percolation, controlling the dispersion of nutrients and making irrigation very efficient.

iTelemeter will allow, in an initial phase, to control the EC level of reclaimed water and automatically make decisions to lower the conductivity (if necessary) through continuous analysis of the conductivity levels at source and in the soil.

For example, if the sensors detect a high level of EC in roots that may be harmful to plants, iTelemeter will make the decision to decrease the conductivity level of the irrigation water as much as possible by mixing it with local water or any other water source with lower EC. The same will be done with the different key parameters, such as nutrients, being measured, until reaching a smart automation that is much advanced and verified by continuous analysis of soil extractions.

So far, the following components of the Smart Fertigation Tool have already been installed, namely: lysimeters, tensiometers and electrical sensors for NPK, humidity, EC, pH and temperature. The electrical sensors have also been connected with IoT controllers (iDatacloud and iTelemeter).

Considering the electrical sensors currently installed in the test site, at the moment we are able to retrieve data of 16 parameters. The final goal is to increase the number of parameters monitored with the SFT up to 30 parameters by the end of P2GreeN, including not only NPK content, humidity or EC, but also irrigation time, duration of irrigation episodes, volume of water applied, etc.

However, in order to calibrate the electrical sensors, there is ongoing lab and field work required. In parallel, a thorough monitoring campaign of local water, reclaimed water, harvested crops and soil for calibration has been established.

Figure 27. Tensiometers, lysimeters and iTelemeter components installed.

Besides optimising the amount of nutrients and water applied to crops, the Smart Fertigation Tool will prevent environmental pollution by controlling potential N and P leaching into the groundwater.

Challenges with scaling up and lessons learnt in the Spanish pilot region
Several challenges and obstacles have been identified since the pilot implementation started. We have divided these obstacles and pain points to consider in two, a) those related to the implementation of the Smart Irrigation Tool, and b) challenges for water reclamation in our pilot.

A) In relation to the Smart Fertigation Tool:

- The calibration of electrical sensors in order to source reliable data on actual levels of nutrients in the soil is an iterative learning-by-doing process, time-consuming and tedious task combining lab and field work
- The calibration is at the same time conditioned by many variables simultaneously (e.g., temperature)
- Variability of specific crops and frequency of data provided

B) With regards to water reclamation:

- It relies on the adequate treatment performance of raw wastewater at the municipal WWTP
- High electrical conductivity and chloride content in municipal wastewater can be an issue – especially in coastal areas
- A real time monitoring of certain microorganisms (e.g., E. coli) will prevent peaks and levels exceeding maximum acceptable values
- Public acceptance (negative perception associated to its use – unless no other choice)

In terms of raw wastewater collection, treatment and reuse, the following challenges are identified:

Table 6. Identified challenges and barriers of the Spanish pilot region rated by their perceived dimensions (red = higher and green = lower barrier).

	Tech	Acceptance	Financial Incentive
Collection at source	Existing sewage system and infrastructure connected to WWTP	No issue	Requested by regulation
Treatment	Tertiary treatment system validated and available in the market (TRL9)	Questions on risk management plan, pathogens, costs per m^3, etc.	Treatment costs higher than using local water (but cheaper than desalinated water)
Reuse	Reclaimed water production done, but Smart Fertigation Tool in development (TRL6)	Certain reluctance from farmers (unless no other choice)	None

In relation to the presence of micropollutants in reclaimed water, the (EU) 2020/741 regulation (Annex II) mentions that additional requirements may be imposed following a risk assessment for specific supplies. In particular, heavy metals, pesticides, disinfection by- products and micropollutants are mentioned in the text. However, no specific compounds and maximum values are identified in the regulation, since the minimum quality requirements do not refer to the above mentioned elements. The Risk Management Plan to be undertaken within P2GreeN will hopefully shed light on the relevance of these parameters in our pilot and determine any further considerations.

Governance readiness level for the Axarquía model

With the recent implementation of the regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, there is a common European legal framework for all member states with provisions to use reclaimed water in agriculture. The regulation contains strict requirements for the quality of reclaimed water and its monitoring. However, although this regulation will be directly applied in each national context, there are a variety of existing regulations in the Spanish and Andalusian context that should be updated. The regulation is providing guidance and assurance to farmers and consumers - with high water quality standards to meet. But complying with other new obligations, such as the submission of a Risk Management Plan, is challenging. This is indeed tackled in P2GreeN as one of our governance solutions foreseen is the preparation of such Risk Mitigation Plan for the Axarquía pilot.

A revision of current Spanish regulation on water reuse (i.e. Royal Decree 1620/2007) is therefore needed in order to adapt to the provisions of the (EU) 2020/741 regulation. Likewise, the procedures for granting licenses to users of reclaimed water shall also be adapted to the new situation by the regional government of Andalusia and water basin authorities, which have the competence for licensing water reuse permits. A revision of the existing legal framework shall be conducted by national and regional actors.

As mentioned, the new EU Regulation includes the implementation of water risk management plans. Requirements are high for farmers and medium for food chain actors. The reason is that farmers consider these requirements to negatively impact the economics of water reuse, while food chain actors consider they are useful to create trust among final consumers.

Thus, it is necessary to adapt national and regional legislation to the provisions of the (EU) 2020/741 regulation, but also develop guidelines to support users of reclaimed water (mainly farmers) to adopt the provisions and meet the standards required by the new legal framework.

The definition of regional governance instruments in P2GreeN will be done together with the local public authorities (AXARAGUA, Algarrobo municipality, Malaga province). The reclamation of wastewater addresses the high risk of droughts in the region and adds up with ecological benefits by reducing the demand for mineral fertilizer as well as the emission of N & P to water bodies, thereby contributing to fulfil the requirements of the Water Framework Directive. The approach has the potential to be widely adapted in southern Spain as well as in the majority of the Mediterranean countries but also in other water-scarce regions throughout Europe.

In P2GreeN, the transferability will be facilitated by defining financial aspects related to water reclamation, securing the compliance with (EU) Regulation 2020/741 on wastewater reclamation, developing a risk management plan, and creating a strategic plan on extending the use of reclaimed water including societal acceptance.

4 Action plan

The internal project plan, presented as Gantt charts, was established and continually updated in collaboration with pilot partners. Milestone 5, "Technology implemented," is set for May 2024. However, Hamburg-Hannover anticipates reaching this milestone by April 2025 due to specific challenges. Monitoring tools for Key Performance Indicators (KPI) and Governance Readiness Level (GRL) charts have been developed. Comprehensive reflections and detailed reports are slated for the demonstration report (D1.1) and the progress report on system readiness (D1.3) in month 24.

The Swedish pilot aims to collect 150 m³ of urine by 2026, producing over one ton of dry fertilizer for barley cultivation. Challenges include encouraging urinal use and exploring partnerships with municipalities, event organizers, and housing complexes to expand urine collection.

Delays at ecovillage hannover (EVH) impact Aurin production, prompting an intermediary step with the Kreiswerke Barnim, a partner in the national project zirkulierBAR project. The VunaNexus urine treatment plant, is underway to advance to TRL 7. EVH planning guidelines for yellow water integration are distributed, and the district-wide collection system is in design planning. Field trials will have to be developed in scale in close alignment with the public authority.

The Spanish pilot focuses on advancing an integrated irrigation fertigation system, targeting TRL 8 by project end. Activities include sensor testing, calibration, and expanding lysimeter use. Biofertilizer production and irrigation targets are progressing, albeit with adjustments. Coordination includes advancing Governance Readiness Level with specific indicators such as Risk Management Plan and adapting regulations.

It is worth mentioning that based on a “Connect the Networks” event held in Zurich with the three national associations NetSan (GER), VaLoo (SUI) and RAE (FRA) in november 2023, there is an ongoing process towards a European network for resource oriented sanitation systems (ROSS). With the mutual force of all Work Packages the Projects aims to join forces with such actors to accelerate the sanitary transformation.

4.1 Sweden implementation

The goal is to have collected during P2GreeN’s runtime a total of 150 m³ of urine and reached a collection rate of 100 m³/year by 2026 (cf. Table 7. Key Performance Indicators for **the Swedish** pilot region and progress planned. With this urine, the aim is to produce over one ton of dry fertilizer which will be used to fertilize 35 000 kg of barley, resulting in the production of 50 000 litres of beer. We are currently at TRL 6 and aim to have a complete and qualified system ready by 2026.

One of the challenges is that people are not using the urinals. S360 is currently testing and developing other ways to make the conventional chemical toilets urine-diverting. However, this will take time and investments. In addition, S360 is in conversation with a few different stakeholders about implementing our urine concentrator technology in permanent settings within the upcoming years. These developing partnerships include municipalities, large event organisers, airports and existing urine-diverting housing complexes.

With the mentioned partnerships forming, we are confident that we will be able to expand the urine collection and achieve our goals.

Table 7. Key Performance Indicators for the Swedish pilot region and progress planned.

KPI Name	Description	Aim in project	Start	End goal	Goal 2023 (Actual)	Goal 2024	Goal 2025	Goal 2026
TRL (overall)	Recycling of source-separated urine through chemical stabilization and evaporation.	Implementation at larger scale, integration into circular value chains	5	8	TRL: 6 (TRL = 6)	TRL: 6	TRL: 7	TRL: 8
Collection of urine	Expansion of collection through partnerships with Touch Down and other partnerships	By end, collect over 150 m³ of urine in total	<5 m^3/y	>150 m^3 total	10 m^3/y (8 m³)	25 m^3/y	50 m^3/y	100 m^3/y
Fertilizer production	To produce a dry concentrated fertilizer from human urine that is tailored for growing barley for beer production.	Increase from small-scale (<50 kg/yr) to large-scale (>1 ton/yr) fertilizer production.	<50 kg/y	>1 ton/r	400 kg/y (On-going ≈ 350 kg)	1000 kg/y	2000 kg/y	4000 kg/y
Malted Barley production	Mass of malted barley produced	Increase from 20 kg to 35 000 kg	20 kg	35 000 kg	80 kg (≈ 75 kg)	3 600 kg	9 000 kg	35 000 kg

4.2 Germany implementation

Based on the above-mentioned delays at EVH, the production of sufficient Aurin for the field trials (9,5 m³) has been at risk. In terms of guaranteeing the execution of the agronomic and ecological research, a cooperation with zirkulierBAR project has been initiated. ZirkulierBAR consortial partner Kreiswerke Barnim GmbH (KWB) has started-up Germany's first VunaNexus urine treatment plant in June 2023, while their partner Finizio is capable of collecting 100 m³ per year. The systems lacks the final of the 3-step process, hence the evaporator foreseen to be installed at the evh building will be temporarily installed at the VN installation at Kreiswerke Barnim.The updated plan requires additional engineering, as well as detailed organisational and financial design of the cooperation and the set-up of contracts between VN, zirkulierBAR and KWB.

Evh planning guidelines for yellow water integration into buildings are published and distributed throughout stakeholders (architects, building technical equipment planning). The planning of the district-wide yellow water collection system is at the state of a design planning and has not matured since the start of P2GreeN. The maturation of the permit planning, which will also provide insights into the governance framework of the innovation, is set on hold due to the above mentioned delays at evh and will be updated as soon as possible.

The nitrite sensor patented by VunaNexus is currently TRL 4 and under development by a high-profile strategic partner. It will be validated in January and precedingly be further tested in the first half of the year 2024 with the goal of reaching TRL 7. Major steps to mature the system towards a fully modular system will be focused on reducing costs and improving the automation (software).

For the Vagtshoff/Goldeimer the next actions planned for the implementation of the value chain are to acquire permit, built and start-up the facilities of the container-based composting process. The grade of the risk management of the floor facilitating the machinery remains to be clarified. The results of the permit and built process will have significant impact on the economics and replication potential of the solution. After start-up, the biological process will demand a narrow process monitoring to be able to optimise the process towards TRL 7.

As mentioned, the administrative decision reduced the size of the planned field trials. Hence, further iterations with the authority will be needed to reach the target of a large-scale field trial.

Table 8. Key Performance Indicators of the pilot region Hamburg-Hanover and progress planned.

KPI Name	Description	Aim in project	Unit	Current Stage	End of Project goal	Goal 2023	Goal 2024	Goal 2025	Goal 2026
TRL (urine treatment)	Recycling of source-separated urine	Implementation at larger scale		6	**8**	6	6	7	**8**
Collection of urine	Scaling up from house-scale to neighborhood-scale	200 inhabitants will collect approximately 100 m³/yr urine	m³/yr	35	**100**	100	100	40	110
Aurin production	Liquid fertilizer production	Large-scale fertiliser production	m³/yr	0	**7,7**	0,5	9,5	10	10

TRL (feacal composting)	Recycling of source-separated feaces through sanitisation and composting	Automation & integration into closed value chains		5	**7**	5	6	7	7
Solid fertilizer production	Produced amount of solid fertilizer	Fertiliser used to grow crops on Vagtshoff farm.	t/yr	0	**40**	0	18,5	16	14
Rye & Barley production	Surface area of cultivated barley with both fertilisers	Apply all fertiliser produced	ha	0	**10**	0	0,16	4,56	4,56

4.3 Spain implementation

One of the key objectives of the Spanish pilot is to advance and further develop an innovative integrated fertigation system which is adapted to the use of reclaimed water, reaching a TRL8 by the end of the P2GreeN project.

As the Water Reclamation Plant used to produce reclaimed water in the pilot is already a validated and demonstrated technology (TRL9), this key objective will be achieved by focusing on developing the Smart Fertigation Tool and Decision Support System for the control and optimization of nutrients and irrigation using reclaimed water.

In this sense, the goal is to advance during the next year 2024 and move from the current TRL6 (technology demonstrated in relevant environment) to reach a TRL7 (system prototype demonstrated in operational environment) in 2025 and TRL8 (system complete and qualified) in 2026 (cf. **Table 9**).

Table 9. Key Performance Indicators related to TRL in the Spanish pilot and progress planned.

KPI Name	Description	Aim in project	Current Stage	End of Project goal	Goal 2023	Goal 2024	Goal 2025	Goal 2026
TRL (OVERALL)	Water Reclamation Plant with Smart Irrigation Tool and DSS integrated	Advance in TRL of integrated irrigation system adapted to the use of reclaimed water generated by the Water Reclamation Plant (tertiary treatment)	9 (WRP), 6 (irrigation system)	8	6	6	7	8
TRL (water reclamation plant)	Water Reclamation Plant (tertiary treatment used instead of RichWater system)	Use of Water Reclamation Plant (tertiary treatment) instead of RichWater (MBR, ETV verified) due to lower requirement of reclaimed water production	9	9	9	9	9	9
TRL (irrigation system)	Smart Irrigation Tool and Decision Support System for nutrients and irrigation control	Advance in TRL of integrated irrigation system adapted to the use of reclaimed water: the irrigation system will be further supplemented by a nutrient monitoring tool to optimise fertilisation and to avoid over-fertilisation of crops irrigated with reclaimed water	6	8	6	6	7	8

To do so, the iTelemeter equipment and the sensors responsible for controlling irrigation are already installed and operational. The process that has been followed with nutrient sensors is based on a first phase where sensors were tested in the laboratory by carrying out tests with reclaimed water, drinking tap water and distilled water. These tests contributed to verify the sensitivity and responses to the different elements in the water. It has also been possible to verify the variations produced by the soil's temperature in the results obtained. However, this testing and calibration phase needs to continue until there is a complete control of the variable ground temperature.

On the other hand, lysimeters have been installed successfully. Lysimeters are devices to extract soil percolating water and they will be used to carry out water extractions. There are a series of lysimeters available for extractions at different points on the plots. Additional and continued samples using the lysimeters are needed to obtain reliable data of certain parameters in soil at different depths (20 cm, 60 cm and 90 cm) and calibrate the electrical sensors.

Extractions are done simultaneously with the dosage of nutrients and irrigation, with the aim of adjusting the sensor values to the real ones. It is therefore necessary to continue working on these sensors, both in the laboratory and on the field, with the final objective of adjusting the values provided as close as possible to the real ones analysed. Finally, the installed nutrient sensors will be providing information on the moments in which there is a fertilisation is provided, reacting very differently to normal irrigation with only water.

Other relevant KPI established in the Spanish pilot relate to the volume of biofertilizer production. The target of producing up to 10 m³/day of reclaimed water has already been achieved and it is expected to continue through the project. There is also a target to reach 1 hectare of surface with the irrigated crops (mango and avocado crops). Due to the limited dimension of the existing test site, it will not be possible to reach this target. Currently, approximately 838 m² are dedicated to cultivation of 120 mango and avocado crops on site. This deviation will, however, not present an issue from the point of view of advancing the TRL of the Smart Fertigation Tool. The field test has been designed so that the three different fertigation treatments are established and tested in each type of crop, every treatment is also duplicated for optimal scientific rigour, and the number of trees per treatment (i.e., 20 trees) is well representative. Nevertheless, the opportunity to test the Smart Irrigation Tool with soil samples from other plots in the proximities will be explored, therefore increasing the variability of soils and crops considered.

Table 10. Additional Key Performance Indicators related to TRL in the Spanish pilot and progress planned.

Indicator name	Description	Aim in project	Current Stage	End of Project goal	Goal 2023	Goal 2024	Goal 2025	Goal 2026
TRL (irrigation system)	Smart Fertigation Tool and Decision Support System for nutrients and irrigation control	Advance in TRL of integrated irrigation system adapted to the use of reclaimed water: the irrigation system will be further supplemented by a nutrient monitoring tool to optimise fertilisation	6	8	8	6	7	8
Biofertilizer production	produce nutrient-rich effluent that complies with national/EU regulation for the use in agriculture (category 2.3)	During P2GreeN, enough quantity of reclaimed water will be generated to irrigate 120 avocado and mango trees	up to 10 m³/d	up to 10 m³/d	up to 10 m³/d	up to 10 m³/d	up to 10 m³/d	up to 10 m³/d
Surface of irrigated crops	Surface area of cultivated avocado and mango crops	1 hectare	838 m²	1 ha	838 m²	838 m²	838 m²	838 m²

Other indicators of high relevance internally established at pilot level relate to the number of fertigation treatments demonstrated, reaching the target of 3 treatments in 2024, once the electrical sensors are sufficiently calibrated to initiate the T3 treatment.

Another indicator related to the number of avocado and mango tree plants. So far, the target of having 120 trees for testing has been reached.

The number of parameters and values provided by the Smart Fertigation Tool is also expected to increase, from 16 parameters available at the moment, to 25 parameters at the end of 2023, 28 parameters in 2024 and up to 30 parameters at the end P2GreeN.

Table 11. Relevant indicators internally established by Spanish pilot and progress planned.

Indicator name	Description	Aim in project	Current Stage	End of Project goal	Goal 2023	Goal 2024	Goal 2025	Goal 2026
Fertigation treatments	comparison of fertigation treatments using local water, reclaimed water, mineral fertilisers	Demonstration of three adjusted fertigation treatments	2 treatments	3 treatments	2 treatments	3 treatments	3 treatments	3 treatments
Avocado & mango trees	Number of trees of each type used in field test	120 trees in total (60 trees each species)	120 trees	120 trees	120 trees	120 trees	120 trees	120 trees
Parameters (Smart Fertigation Tool)	Number of parameters monitored with Smart Irrigation Tool	30 parameters	16	30	25	28	30	30

Very important for the Spanish pilot is also to coordinate an action plan to advance in the Governance Readiness Level (GRL) on the region. For this, four different indicators have been established, namely:

- Risk Management Plan according to EU Regulation 2020/741
- Adaptation of Spanish Royal Decree 1620/2007
- Roadmap to extend the use of reclaimed water in the Axarquía region
- Guidelines for authorities to implement adequate water pricing and tariff structure

With the active collaboration and contribution from other P2GreeN partners, the goal is to advance from the current GRL3-4 up to GRL7 by the end of the project, providing the specific plans, policy recommendations, and guidelines.

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6 ANNEX

6.1 Gantt Chart Pilot Region Gotland

	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Milestones												M1						M5																		M8		M9			M10 / M11							
Deliverables												D1.6						D1.6										M5			D1.2 / D1.4					D1.1 / D1.3										D1.5		
Task 1.1 Set up, operation, demonstration and validation in pilot regions																																																
1.1.1 Drying tech TRL Increase from 5 to 8																																																
optimizing the Acid drying		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																				
Connection with waste heat												■	■	■	■	■	■																															
Permission for Urine transport												■																																				
Designing new drying system												■	■																																			
Building new drying System													■																																			
Installation of new system													■	■	■																																	
Testing and optimization of new system														■	■	■																																
Start-up of operations of drying															■	■	■	■	■	■	■	■																										

Evaluation and monitoring
Modifications of drying
1.1.2 Stabilising Urine tech TRL Increase from 5 to 8
Optimizing the urine stabilisation
Logistics planning
Chemical stabilizer purchasing
Packaging supplies Selection
Packaging supplies Purchase
Evaluation of suppliers
Plan for scaling-up packaging
Purchase items for scaling-up
1.1.3 Fertilizer production tech TRL increase from 5 to 8
Testing machinery
Lostics plan value chain
supply mgmt of raw material

Optimising final drying stage																																																
Procurement of pelletizing																																																
Evaluation of process																																																
Evaluation of fertilizer performanc																																																
1.1.4 Urine collection Logistics (>5m^3/yr to >100 m^3/yr)																																																
Plan for urine collection																																																
Logistics of urine collection																																																
Evaluation of collection																																																
1.1.5 Beer Production																																																
Barley Growing																																																
WP2 Data collection																																																
Barley Harvest																																																
Barley Malting																																																
Beer Production																																																
Evaluation																																																

6.2 Gantt Chart Pilot Region Hamburg-Hanover

	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Milestones											M1																M5								M8			M9			M10 / M11							
Deliverables (updated)											D1.6							D1.6													D1.2 / D1.4						D1.1 / D1.3									D1.5		
Task 1.1 Set up, operation, demonstration and validation in pilot regions																																																
1.1.1 zirkulierBAR design, set-up, operation, demonstration and validation of urine treatment and Aurin production																																																
commercial contract ecovillage/Kreiswerke Barnim												■	■																																			
cooperation contract P2GreeN/zirkulierBAR												■	■																																			
permission from construction authority to extend the research facility												■	■	■																																		
engineering and planning of the facility extension												■	■	■																																		
order of the distiller												■																																				
installation of distiller facility & peripheric installations															■																																	
installation of distiller & integration into existing system															■																																	
start-up of operations (urine collection & Aurin production)															■																																	
production of Aurin																■	■	■	■	■	■	■	■	■	■	■	■																					

logistics - transport of Aurin to Vagtshoff
logistics - transport of distiller to ecovillage hanover
1.1.2 evh Pilot design, set-up, operation, demonstration and validation of urine treatment and Aurin production
Pilot design & engineering
water treatment and discharge permit
installation of toilets
installation of collection & overflow network
installation of vunanexus treatment facility
start-up of operations (urine collection & Aurin production)
Logisitcs: Dry toilet solid matter transport from evh to GE
logistics: transport of Aurin from evh to Vagtshoff
validation, maintenance & optimisation of operations

1.1.3 GE Pilot design, set-up, operation, demonstration and validation of feacal composting and solid fertilizer production																																																
procurement of machinery	■	■	■	■	■	■																																										
start-up composting containers	■	■	■	■	■	■										■	■																															
construction permit										■	■	■	■	■																																		
construction of facility grounds															■	■	■																															
supply management of raw material									■	■	■							■	■	■	■	■	■						■	■	■	■	■	■	■													
Validation compost production operations																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
supply of product for field trials															■							■																	■									
1.1.4 Fertigation - Design, permit and Set-up of field trials for fertilizer application and it's validation																																																
viable indication for application of recycling fertilizers	■	■	■	■	■	■	■	■	■							■	■	■	■	■	■																											
supply of sufficient product for field application															■		■					■						■		■									■		■							
application (planning, testing machinery & methods, validation)															■	■	■	■	■	■	■	■						■	■	■	■	■	■						■	■	■	■	■	■	■			
Soil, Crops & Nutrient mgmt															■	■	■	■	■	■	■	■						■	■	■	■	■	■						■	■	■	■	■	■	■			
monitoring of parameters															■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						■	■	■	■	■	■	■			
Harvest (rye and barley)																				■												■												■				

6.3 Gantt Chart Pilot Region La Axarquia

		2023												2024												2025												2026										
	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Task 1.1 Set up, operation, demonstration and validation in pilot regions																																																
1.1.1 Pilot design and installation of modules																																																
Pilot design	■	■	■	■																																												
greenhouse replacement			■	■																																												
Greenhouses installation				■	■																																											
preparation of ridges for avocado field				■	■																																											
Installation of irrigation system					■	■																																										
Installation of lysimeters and tensiometers					■	■	■	■	■	■	■																																					
Installation of sensors					■	■	■	■	■	■	■	■	■																																			
Installation of fertilisation system										■	■	■	■																																			

1.1.2 Crops and soil mgmt																																																
Crops planting																																																
Crops mgmt. and monitoring of parameters											x				x						x		x				x						x		x				x						x		
Soil mgmt. and monitoring of parameters																																																
Harvest mango and avocado															A						M						A						M						A						M		
1.1.3 Production of biofertilizer and fertigation																																																
monitoring of reclaimed water parameters																																																
fertigation treatments																																																
monitoring of lysimeters																																																
Optimization of fertigation water																																																
1.1.4 Development of the Smart Irrigation Tool and DSS																																																
Calibration of sensors																																																
Phase I: Beta version of Smart Irrigation Tool																																																
Phase II: Remote control (= DSS)																																																
Validation by end-users of the stable version																																																

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