# A TOILET PAPER

## Sustainable Sanitation Solutions for Municipalities



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**A Toilet Paper**
Sustainable Sanitation Solutions for Municipalities

Master Thesis (Part I)

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# Part I

# 01 What

## 1.1 Context

In order to achieve the global sustainability goals of the United Nations, we need to rethink the use of limited resources. Climate change and resource scarcity demand a change in our production and consumption behavior from linear to circular material flows. Food production in particular is dependent on resources such as water, soil, seeds, and especially nutrients such as phosphorus and nitrogen. Phosphorus is mined for fertilizer production from limited rock phosphate deposits with consequences for humans and the environment. The German regulation on the reorganization of sewage sludge utilization (Neuordnung der Klärschlammverwertung) therefore requires phosphorus to be recovered from 2029 onwards. In a motion to the federal government „Wasser- und Sanitärversorgung für alle nachhaltig gewährleisten“ of May 12, 2020, the parliamentary groups of the CDU/CSU and SPD demand that the German Bundestag should take action to ensure that the sanitary sector is understood as a business sector, in which human waste can be used as a resource in the sense of a circular economy. This is the starting point for this proposal.

## 1.2 Objective

This research proposal aims to analyze opportunities for sustainable sanitation systems in municipalities with a focus on public toilets in Germany. In order to introduce the topic, the global importance of sustainable sanitation and recycling of nutrients will be outlined. This will define the *why*. The second part of this proposal will focus on the how, investigating possibilities for the recycling of nutrients from feces and urine. Different sanitary systems and toilet interfaces will be examined as well as the material flow in the current sewage system and off grid solutions. Special focus is put on the use of dry toilets as an alternative to flush toilets. The next part will take a closer look at the *who* by analyzing pioneers and pilot projects for sustainable sanitation in Germany. This research proposal will focus on German municipalities, since sanitary systems in the public space are a direct service provided for the citizens. Particular emphasis is put on the region Barnim / Eberswalde as it offers public dry toilets and is home to the company *Finizio*, which runs Germany's only pilot plant for processing the collected contents to produce humus fertilizer. This proposal aims to investigate factors for success that contribute to the development of such a pilot plant and the use of dry toilets in cities. Who are the stakeholders that are involved? What are necessary conditions for realizing such innovative projects in municipalities? The goal is to derive insights for other municipalities to implement innovative sanitation solutions. In order to identify the potential for transferring the solution to other municipalities, the public toilet ecosystem of the City of Cologne will be investigated. Who are the correlating stakeholders in Cologne? Are they aware of the innovation potential within the sanitary field? What is the City's strategy concerning sustainability and climate change mitigation? These questions will be addressed in this research proposal. It concludes with an outlook and potential opportunities for designing interventions.

# 1.3 Approach

This work follows the service design approach, in which complex systems are analyzed holistically. The aim is to understand the perspectives of relevant stakeholders within a given system, by applying desk as well as qualitative research and visualization. [1]

The iterative process for doing so is generally divided into different phases: exploration, creation, reflection and implementation.[2] This research proposal covers the exploration phase by focusing on desk research and the discovery of ecosystems for innovative sanitation in Germany with special emphasis on the region of Barnim / Eberswalde and Cologne. The ecosystems will be analyzed through qualitative research in the form of interviews in coordination with the research project *zirkulierBAR*. The project is funded by the German federal Ministry of Education and Research and includes eleven partners. Among others, the *Fraunhofer Center for Responsible Research and Innovation at Fraunhofer IAO* (CeRRI), the *Hochschule für Nachhaltige Entwicklung Eberswalde* (HNEE), the *TU Berlin*, the *Leibniz Institute for Vegetable and Orchard Crops* (IGZ), *Finizio*, the county of Barnim, the *Kreiswerke Barnim* (KWB) and the city of Eberswalde are working together to build an innovative and scalable recycling plant for the treatment of contents from dry toilets. It aims to prove that recycled fertilizers are safe to use in agriculture, rich in nutrients and low in pollutants. In the long run, a blueprint for a treatment plant, that can be adopted by other municipalities as an alternative to the linear wastewater treatment systems existing today is sought to be established.[3] Based on the findings and insights within this proposal, the second phase of the service design approach will follow: creation. The development of ideas as well as prototyping and testing will be described in the master thesis. The results of this work will be considered in the research project *zirkulierBAR* and shall contribute to the overall change towards sustainable sanitation and a circular material flow.

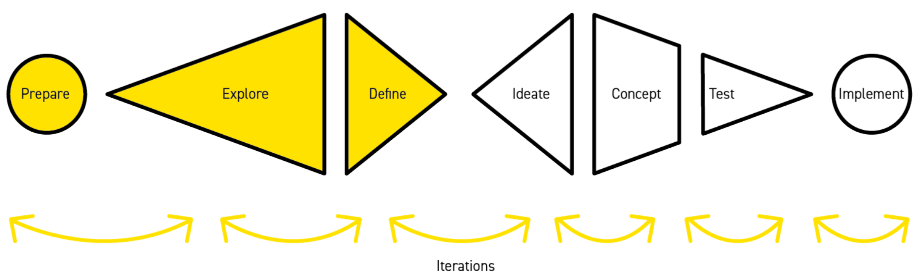


Fig. 1: Service Design Process

1 Stickdorn, Hormess et al. 2018, p. 24 ff.
2 Mager, Gais 2009, p. 68 ff.

3 *zirkulierBAR*: REGION.innovativ 2022.


What

# 02 Why

## 2.1 Sustainable Development Goals

Regardless of our age, gender, or location on this planet, even within this universe: every day we all need one place to go to: a toilet. Since 2010 the access to safe sanitation and clean drinking water is recognized as a human right by the United Nations. However according to the World Health Organization 2.0 billion people still do not have access to basic sanitation facilities in the year of 2020. As a result, inadequate sanitation leads to 432 000 deaths caused by diarrhea every year. In addition, the transmission of other diseases like cholera, dysentery, hepatitis A, typhoid and polio is accelerated. Poor sanitation also slows down the social and economic development of affected people. Human wellbeing is further reduced due to the risk of sexual assault, anxiety and the loss of educational opportunities.[4] Thus, the sixth Sustainable Development Goal (SDG) of the United Nations calls to ensure "the availability and sustainable management of water and sanitation for all".[5] The second SDG calls to "end hunger, achieve food security and improve nutrition and promote sustainable agriculture".[6] In order to feed the global population two additional elements are just as important to agriculture as water: phosphorus and nitrogen. The following chapter focusses on the importance of these two nutrients and the problems and environmental challenges they pose. This way it can be examined how a redesign of sanitary systems could contribute to solving the issues of both clean sanitation and world hunger.

4 WHO, 2022.
5 United Nations, n.d..
6 United Nations, n.d..

# 2.2 Nutrients

### 2.2.1 Phosphorus

The chemical element Phosphorus (P) naturally mostly occurs in the form of phosphate ($PO_4$) and can be found predominantly in the lithosphere, the earth's crust. It is a non-renewable raw material which is mined as phosphate rock.[7] Phosphorus is required by all living organisms, as it is responsible for cellular energy transfer as well as the transfer of genetic information like DNA and RNA. It is therefore essential for every living cell and a common ingredient in agricultural fertilizers.[8] Over 70% of the global phosphate deposits can be found in Morocco and the Western Sahara, while China, northern Africa and the United States also provide to the global demand.[9] Germany is completely dependent on importing raw phosphate or already processed phosphate fertilizers. The annual consumption of said fertilizers used in agriculture in Germany amounted to 211.000 tons in 2018.[10]
As with most natural resources, phosphate is also a strategic resource with the potential for conflict. Morocco's phosphor reserves are a result of the annexation of the Western Sahara, which was not recognized by the United Nations. Furthermore, the European Union imports most of its phosphorus from Russia,[11] which is particularly relevant in the context of Russia's invasion of Ukraine.
Another problem of mining phosphorus is the decrease in its quality. Contamination with heavy metals such as cadmium and radionuclides such as uranium pose risks for humans and the environment.[12] Furthermore, the global phosphorus demand could reach a peak where it can no longer meet the increased demand. This point is called peak phosphorus, similar to peak oil. Unlike oil, which can be replaced with renewable energy sources, "there are no substitutes for phosphorus in agriculture"[13] as concluded by the U.S. department of the interior in 2022. Estimates for reaching peak phosphorus vary from 50 to 350 years in the future.[14] Due to its economic relevance, phosphate rock was included in the list of critical raw materials by the European Commission in 2014.[15] Germany also adjusted its regulations and obliges wastewater treatment plants to start technically recycling phosphorus. Further details on these regulations are to be found in the following chapter.

The following graphic illustrates a simplified phosphorus cycle in order to outline the global material flow. Sedimented phosphate leaches out into the environment through the process of weathering. As outlined before, phosphate rock is also mined for fertilizer production. These fertilizers

7 Roskosch and Heidecke, 2018, p. 46.
8 Scheerer et al., 2019, p. 2.
9 U.S. Geological Survey, 2022, p. 125.
10 Statista, Phosphatdünger, n.d..
11 Roskosch and Heidecke, 2018, p. 47.
12 Roskosch and Heidecke, 2018, p. 47.
13 U.S. Geological Survey, 2022, p. 125.
14 Mnthambala et al., 2021, p. 1.
15 Baranzelli et al., 2017, p. 7.



Why

are applied to agricultural fields, so that microorganisms such as bacteria and fungi decompose organic phosphates which are then returned to the soil, making it available for plant absorption.[16] Human excreta in Germany on the other hand mostly end up in waste water treatment plants. While the resulting sewage sludge can be used as agricultural fertilizer, the application is legally regulated and progressively restricted in order to prevent the transmission of pathogens and the pollution of soils and aquatic systems. This is done mainly to protect humans and the ecosystems from pharmaceutical products such as antibiotic residues and other substances like nanomaterials and microplastics.[17]

The agricultural utilization of sewage sludge, sewage sludge mixtures and composts amounted to 16,38% in 2020. The largest amount of sewage sludge, 76,7% in 2020, is disposed through mono- or co-incineration in different plants like coal-burning power plants, cement or waste incineration plants.[18] The ashes are mostly used as building materials, removing phosphorus from the cycle.[19] In conclusion, the amount of available phosphorus element is continually being decreased.[20] The following chapters therefore investigate recycling opportunities for successfully closing the phosphorous cycle.

16 Umweltbundesamt, 2018.
17 Roskosch and Heidecke, 2018, p. 45.
18 Statista, Entsorgung von Klärschlamm in Deutschland nach Entsorgungswegen im Jahr 2020, 2020.
19 Roskosch and Heidecke, 2018, p. 40.
20 Ibid., p. 41.

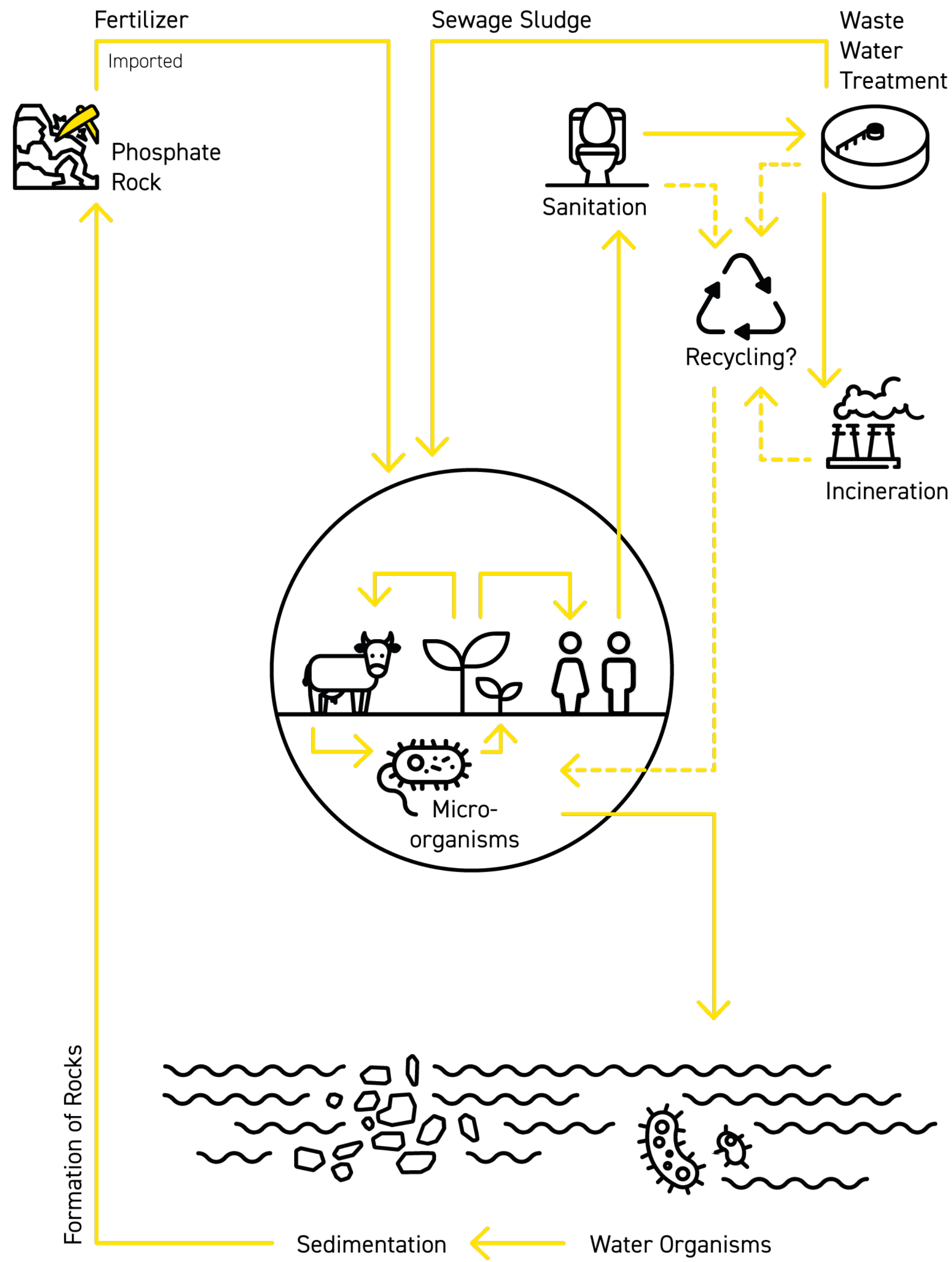


Fig. 2: Phosphorus Cycle

### 2.2.2 Nitrogen

Another cycle that needs to be considered in agriculture is the nitrogen cycle, as can be seen in Figure 3. Nitrogen (N) is the main component of the atmosphere with an amount of a 78%.[21] Humans as well as animals need nitrogen for their bodily functions. It is absorbed through plant and animal protein. Plants assimilate nitrogen directly from the soil in the form of ammonium ($NH_{4+}$) and nitrate ($NO_{3-}$) and use it for their protein synthesis. Nowadays, nitrogenous fertilizers are indispensable for ensuring high agricultural yields. In former times the only natural nitrogen sources were manure, guano and saltpeter storage sites. Due to Fritz Haber's invention of industrial ammonia ($NH_3$) synthesis from atmospheric nitrogen in 1909, the production of fertilizer from the air allows for increased yields and food production. The so-called Haber-Bosch process of industrially synthesizing ammonia is highly energy consuming. Today, ammonia synthesis and fertilizer production account for approximately 2% of the global energy consumption.[22] For every ton of $NH_3$ produced, two tons of carbon dioxide are released.[23] Providing the steadily growing global population with sufficient food would not be possible without the use of $NH_3$ fertilizer. Furthermore, the intensive use of fertilizers in agriculture as well as the production of meat also contribute to the pollution of ecosystems.[24] The import of soy as animal feed drives global flows of nitrogen. The animals absorb only parts of the nitrogen contained in their feed and the rest is exerted as manure. In regions with intensive livestock farming, which is often not restricted and therefore unbalanced with the available land, this can lead to a manure surplus. As a result, more manure is produced than can be utilized on the agricultural fields. Even through there are regulations on manure application, which often lead to the exchange and transport to other agricultural areas, there can be locally increases of nitrate ($NO_3$) emissions into the soil and groundwater and ammonia ($NH_3$) into the air.[25] This can lead to the pollution of ground- and drinking water and eutrophication of marine and costal ecosystems as well as the acidification of soils, affecting biodiversity. As outlined, the main sector for nitrogen emissions in Germany is the agricultural sector.[26] Other major emission sources are the mobility sector and power industry emitting nitrogen oxide ($NO_x$) due to combustion processes. Nitrogen is also discharged to surface waters from municipal wastewater treatment plants and urban sewer systems amounting to 22% of the total nitrogen and 33% of the total phosphorus emissions in 2016.[27] Municipalities in Germany use up to 20% of their energy demand for municipal services to remove nitrogen from wastewater.[28] Therefore the nitrogen cycle and the system for treating waste water and sewage sludge offer an opportunity for saving energy and reducing emissions.

21 Umweltbundesamt, 2021, p. 9.
22 Ibid., p. 7.
23 Kugler et al., 2015, p. 52.
24 Wissenschaftliche Dienste Deutscher Bundestag, 2018, p. 4.
25 Umweltbundesamt, 2021, p. 7.
26 Ibid., p. 9.
27 Umweltbundesamt, 2021.
28 Fricke, 2009, p. 3.

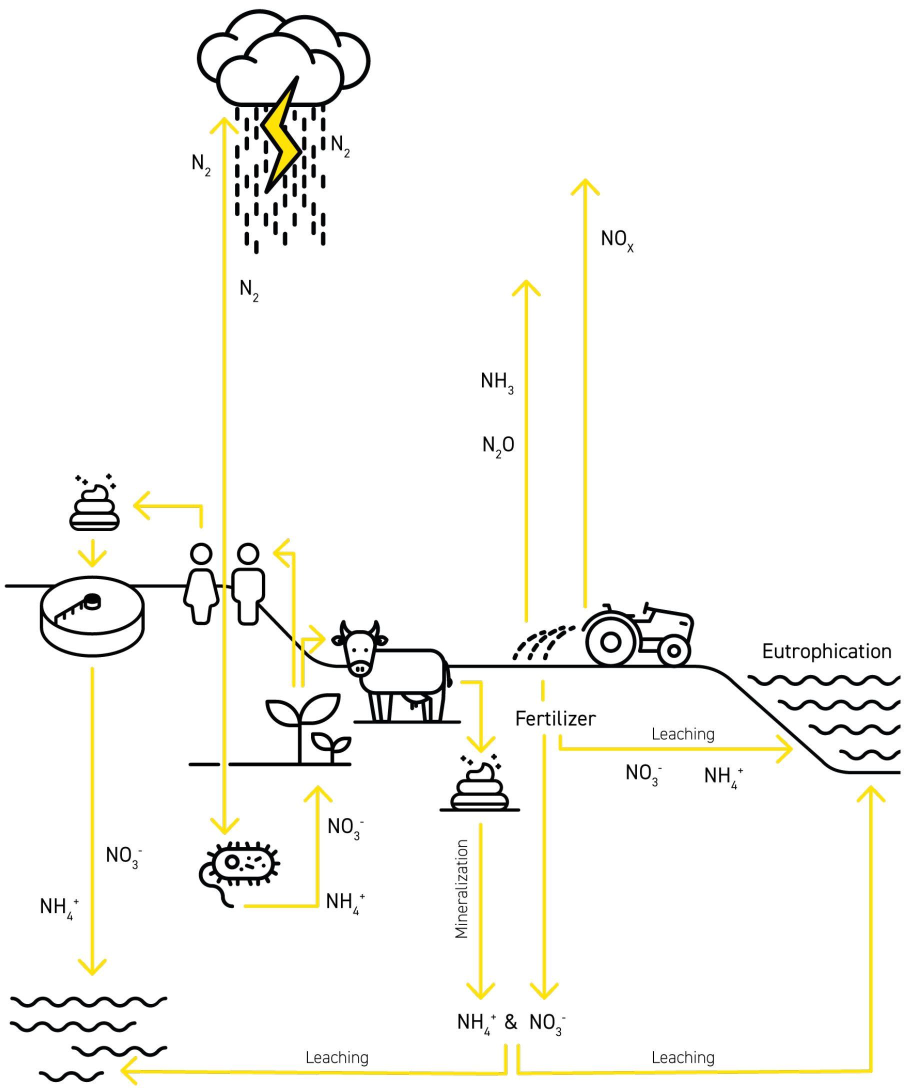


Fig. 3: Nitrogen Cycle



# 2.3 Regulations

### Fertilizer regulations

There are various regulations for the application of fertilizers, containing phosphorus and nitrogen, in agriculture like the fertilizer act (Düngegesetz - DüngG), the fertilization regulation (Düngeverordnung - DüV) and the fertilizer regulation (Düngemittelverordnung DüMV). The purpose of the DüngG is to ensure crop nutrition and a high-quality product supply to the population, while maintaining soil fertility and preventing hazards to humans and animals from fertilizers. It calls for the sustainable and resource-efficient use of nutrients in agricultural production and the avoidance of nutrient losses to the environment. According to § 3 section 2, fertilizers should be applied according to the good professional practice (gute fachliche Praxis). It determines that the type, quantity and timing of application should be tailored to the needs of the plants and the soil.[29] The DüV specifies the good professional practice. It contains restrictions on the application of fertilizers that contain nitrogen and phosphates depending on the location and soil condition. It also defines periods and conditions when fertilizers cannot be applied for example when the soil is flooded, waterlogged, frozen or snow-covered. Furthermore, it specifies requirements for the storage of organic fertilizers.[30] The DüMV regulates the introduction of fertilizers as well as soil additives, culture substrates and plant aids.

29 Bundesministerium der Justiz, DüngG.
30 Bundesministerium der Justiz, DüV, 2017.

Like manure, sewage sludge is listed in annex 2, table 6 of the DüMV and therefore approved as organic or organic-mineral fertilizer. The ashes from incinerated sewage sludge and other recyclates from phosphorus recovery (phosphate precipitation, smelting gasification) are also permitted as phosphate fertilizers. Paragraph 5 of the DüMV specifies disease and phytohygiene parameters for use of sewage sludge.[31] It regulates the general fertilizer application and allows exceptions for research or experimental purposes.[32]



31 Bundesministerium der Justiz, DüMV.
32 Bundesministerium der Justiz, DüMV.

# 03 How

## 3.1. Traditional Sanitation Systems

In order to understand the systems and flow of nutrients in feces and urine, one needs to take a closer look at sanitation systems and technologies. This chapter will describe the sanitation system on a systematic level. “The Compendium [of Sanitation Systems and Technologies] defines sanitation as a multi-step process in which human excreta and wastewater are managed from the point of generation to the point of use or ultimate disposal. A Sanitation System is a context-specific series of technologies and services for the management of these wastes (or resources), i.e., for their collection, containment, transport, transformation, utilization or disposal.”[33] Depending on the context and location one can differentiate between water-based and dry technologies. Furthermore, the management can be divided into levels, ranging from household, shared to public level. Each system also includes services like management, operation and maintenance.[34] The general logic of sanitation systems can be described as a system processing an input, followed by a technology generating an output.


Fig. 4: Simplified Sanitation System

33 Tilley et al., 2014, p. 10.
34 Ibid., p. 10.

The logic can be further specified into the following stages:

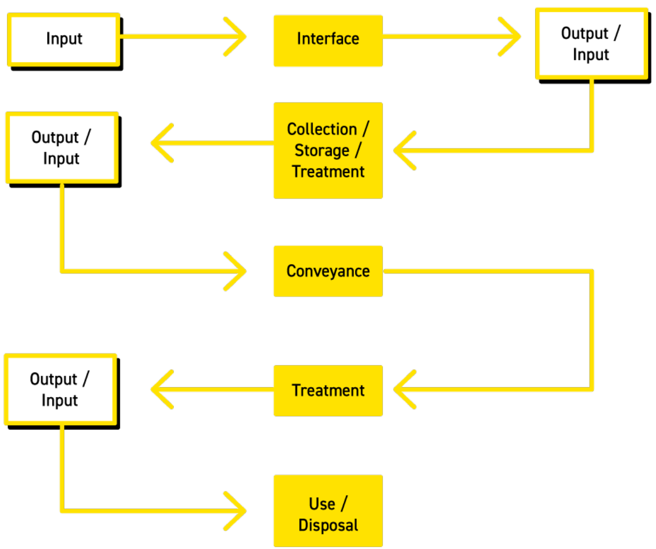


Fig. 5: Detailed Sanitation System



### 3.1.1 Inputs

The following products can be classified as inputs:

- Urine
- Feces
- Menstrual blood
- Vomit
- Dry cleansing material
- Anal cleansing water
- Flush water
    - Freshwater
    - Rainwater
    - Graywater
- Chemicals
- Cleaning detergents
- Disturbance materials

## Urine

Humans produce an average amount of 1.42 liters of urine per day.[35] The liquid contains the largest fractions of nutrients like nitrogen and phosphorus and organic solids like urea that leave the body. The annual nutrient amounts up to 4 kg of nitrogen and 0,55 kg phosphorus per person, depending on the persons diet.[36] Urine therefore contributes to approximately 80% of the nitrogen, 55% of the phosphorous and 60% of the potassium in domestic wastewater. In relation to the overall amount of waste water, urine constitutes less than 1% of the total waste water volume.[37]

## Feces

The annual volume of excreted feces amounts to around 50 liters per person.[38] Depending on the intake, healthy individuals defecate about 1.2 times per day. The excreted feces are composed of about 80% of water. Further materials are carbohydrate, fiber, protein, fat as well as bacterial biomass.[39] The nutrients contained in feces amount to 12% of nitrogen and 39% of phosphorus.

## Menstrual blood

Another human-induced input is menstrual blood. It enters the system either directly, mostly in combination with urine and / or feces or is disposed with menstrual hygiene products like tampons or sanitary pads

35 Rose et al., 2015, p. 1856.
36 Schönning, 2001, p. 3.
37 Ibid., p. 3.
38 Tilley et al., 2014, p. 11.
39 Rose et al., 2015, p. 1827.





or napkins. These products should usually be treated along with general waste and disposed separately.[40]

## Vomit

Due to gastrointestinal infections diarrhea and vomit can occur. Viral as well as bacterial pathogens can cause an infection. The most common ones are noroviruses and rotaviruses and bacterial pathogens such as Salmonella, Campylobacter or Escherichia coli species. Vomit is a transmission medium for diseases just like feces. Even if this input occurs in low concentrations compared to feces, it needs to be considered as a relevant input in terms of epidemic hygiene.[41]

## Dry cleansing material

These materials are used to wipe oneself after defecating and or urinating. They vary depending on the context and range from toilet paper to leaves, rags, corncobs or stones. These materials are either disposed into the toilet or separately collected which depends on the following systematic points like collection and treatment technology.[42]

## Anal cleansing water

In contrary to the use of dry cleansing martials, water can also be used to cleanse oneself after defecating and or urinating. Stationary or portable bides as well as smart toilets with integrated bidets, jets or hand splashed water can be used. One person uses approximately 0.5 to 3 liters of water per cleansing.[43]

40 Ibid., p. 11.
41 Krause et al., 2020, p. 8.
42 Tilley et al., 2014, p. 11.
43 Ibid., p. 11.

### Flush water

Flush water can be freshwater, rainwater or graywater that is used to transport toilet inputs from the interface to further stages of the sanitary system like collection, transformation, utilization or disposal. It is also used for cleaning the interface.[44] 94% of the German population are connected to the sewage system and therefore utilize some sort of flush water.[45] The average person in Germany uses about one third of their fresh water consumption for flushing the toilet.[46]

### Chemicals

Chemical toilets use sanitary additives. These can be either mostly harmless and slow working enzyme-based additives that cause an aerobic decomposition of feces, or biocidal additives. The latter, more common additive liquids inhibit the biological putrefaction processes, decrease odors and mask feces with color and odor.[47] The oftentimes bluely colored liquids can contain formaldehyde, paraformaldehyde, glutaraldehyde, glyoxal or quaternary ammonium compounds as biocidal agents. They prevent the anaerobic digestion process by inhibiting bacterial growth or killing bacteria.[48] The contents of chemical toilets need to be diluted in order to be treated in a wastewater treatment plant. The Bavarian State Office for Water Management states that a 20-fold dilution is appropriate. This is done to ensure the purification efficiency of the biological stage in waste water treatment plants, which could otherwise be reduced or completely eliminated with corresponding consequences for the receiving aquatic ecosystem.[49]

### Cleaning detergents

Various cleaning agents and detergents are disposed into waste water ranging from laundry detergents, fabric softeners, to dishwashing detergents and cleaning agents. The consumption in Germany amounts to about 1.3 million tons of detergents and cleaning agents every year. [50] They contain a variety of substances like surfactants, alkalis or acids, enzymes, optical brighteners, fragrances, preservatives, disinfectants, organic solvents and microplastic. These substances pose a challenge to wastewater treatment, since they can pollute the environment by entering aquatic systems and accumulating in organisms as they are oftentimes difficult to degrade.[51]

### Other materials / Disturbance material

Materials such as sanitary products, glass, garbage[52], needles or condoms[53] can be classified as disturbance materials in toilets and should be disposed separately.

44 Ibid., p. 11.
45 Fricke, 2009, p. 3.
46 Statista, 2021, Verwendung von Trinkwasser in deutschen Haushalten nach Verwendungsart im Jahr 2021.
47 Adam and Abwassertechnische Vereinigung, 1997, p. 8.
48 Ibid., p.10.
49 Bayerisches Landesamt für Wasserwirtschaft, 2000, p. 3.
50 Bundesministerium für Umwelt and Umweltbundesamt, 2017, p. 63.
51 Ibid., p. 64.
52 Krause et al., 2020, p. 3.
53 Interview with EcoToiletten Berlin, (22.02.2022).

### 3.1.2 Outputs

**Blackwater**
A mixture of urine, feces, flush water, anal cleansing water and dry cleansing material constitutes blackwater.[54]

**Brownwater**
Feces, flush water, anal cleansing water and dry cleansing materials without urine is classified as brownwater.[55]

**Excreta**
Urine and feces which are not mixed with flush water are called excreta.[56]



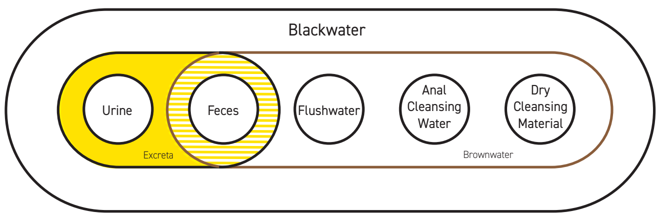


Fig. 6: Definition of Blackwater, Brownwater and Excreta

54 Tilley et al., 2014, p. 10.
55 Ibid., p. 10.
56 Tilley et al., 2014, p. 11.



**Heat**
When wastewater from buildings is discharged into the sewer system, heat is also discharged and mostly wasted. The heat can be regained through trough heat exchangers and heat pumps. It can either be extracted in the buildings, the sewers or at waste water treatment plants. Wastewater offers an opportunity for a regenerative energy supply that can be used to heat houses, office buildings or public facilities. In Germany around 60 plants for recycling heat from waste water have been built and such projects are being promoted by innovation programs.[57]

**Sewage sludge**
Sewage sludge originates from sewer-based waste water collection and can be categorized into stabilized primary, secondary, and tertiary sludge.[58] It is a mixture of excreta, water, sand and trash. Depending on the category, it consists mainly of organic substances and contains various compounds such as nutrients (including nitrogen and phosphorus), heavy metals, drug residues, pathogens and various anthropogenic micro- and nanoscale constituents.[59]

**Effluent**
The liquid that leaves waste water treatment plants is called effluent. It is disposed into water bodies after passing first, secondary and tertiary treatment (see chapter 4.1.3).[60]



57 Bundesministerium für Umwelt and Umweltbundesamt, 2017, p. 170.
58 Roskosch and Heidecke, 2018, p. 18.
59 Tilley et al., 2014, p. 12.
60 Ibid., p. 10.

### 3.1.3 Interfaces

The inputs named above mostly occur in various combinations: feces plus toilet paper, urine + feces, menstrual blood + urine etc.[61] They enter the sanitation system through an interface. In a sanitary system the toilet can be classified as the user interface. It is the intersection between humans and the following functional structures that collect, contain, transport, process and use or dispose the inputs. The use of a toilet could therefore be classified as a human-machine interaction (HMI). The interfaces vary depending on their context, location, the availability of water and range from toilets, pedestals or pans to urinals.[62]

**Interfaces and systems in context**

As described before, sanitary systems are always context-specific and so are their interfaces and technologies. The following analysis focusses on the context of sanitation in Germany. In order to identify and outline opportunities for nutrient recycling, the interfaces and systems currently used in public toilets are described. The overall spectrum of toilet interfaces and the following technologies is broad and includes low tech solutions like pit latrines, peepoobags, septic tanks and more. The other end of the spectrum features high tech solutions like vacuum toilets, toilets with integrated bidets, heated seats, automated cleaning, music or sound, and smart toilets with optical methods and artificial intelligence that analyze feces and urine for health monitoring. These high- and low-tech systems do not constitute the focus, as they are not relevant in the context described. At first the emphasis is put on toilets that are connected to the sewage system, as well as mobile chemical toilets. Thereafter dry toilet solutions will be outlined to illustrate innovative opportunities for alternative solutions for recycling nutrients.

The following systems describe different interfaces and the following functional structures including collection, treatment and use or disposal.

61 Krause et al., 2020, p. 3.
62 Tilley et al., 2014, p. 13.

**Flush toilet**

A flush toilet uses water to flush feces, urine, menstrual blood and cleansing material down the sewer. Flush toilets can either have a sitting or squatting interface. They are usually made of a porcelain bowl and a water tank with a pushing or pulling lever to trigger the flushing mechanism. These toilet types have a water seal that prevents odors from coming up through the plumbing and sewer.[63] Older toilet models use approximately 9 to 14 liters of water per flush. Modern toilets require 6 to 9 liters.[64]

There are water saving technologies like pressure flushers that can reduce the amount of flush water to about 3 liters. These require a suitable interface that works with fewer water. The average flush water use per person amounts to approximately 34 liters per day.[65] This offers a great potential for saving water.[66] With a flush the inputs of the system are transported through the sewers and treated in a waste water treatment plant (see chapter 3.1.4).

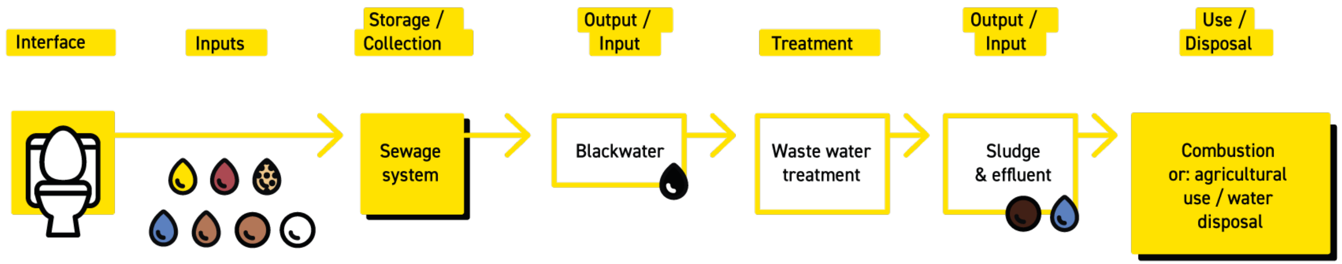


Fig. 7: Systematic Visualization: Flush Toilet

63 Ibid., p. 52.
64 BMUV, 2016.

65 Suhr, 2021.
66 BMUV, 2016.

### Urinals

Urinals are used for exclusively collecting urine. There are water-based as well as waterless models, which, depending to their technical complexity, may feature odor seal mechanisms. These mechanisms range from mechanical solutions to membranes or sealing liquids, preventing malodors to occur. Urinals are by default diverting interfaces that allow separate urine collection. Models for men are mostly wall-mounted units even though squatting interface also exist. Urinals for women are less common but become increasingly popular.[67]

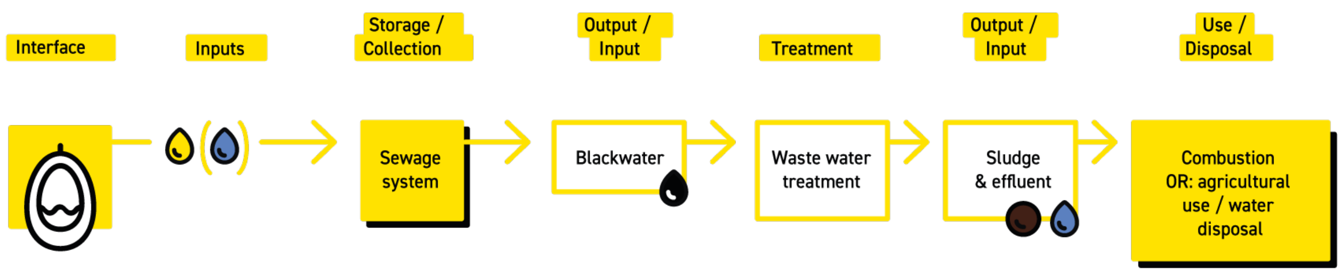


Fig. 8: Systematic Visualization: Urinal

67 Tilley et al., 2014, p. 48.

**Chemical toilet**

Chemical toilets are portable single units mostly constructed out of plastic that are not connected to the sewage system. Each unit commonly has a 200 L holding tank capacity that can be used up to 75 - 100 times before it needs to be desludged. The tank contains sanitary additives. As outlined before, these chemical additives decrease odors and mask excreta. Chemical toilets are available with different interfaces for sitting or squatting, depending on the context, and are equipped with a washable floor and ventilation pipes. Integrated urinals as well as larger models for wheelchair access and advanced models with handwashing stations within the toilet unit are available on the market. The collected contents are emptied with a desludging vehicle. The access for these motorized emptying vehicles needs to be considered when setting up a chemical toilet.[68] The vehicles must be emptied at fecal sludge discharging stations usually at sewage treatment plants.[69]

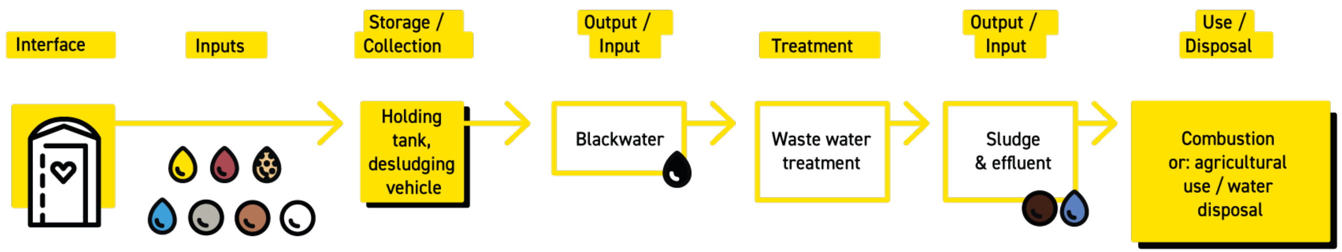


Fig. 9: Systematic Visualization : Chemical Toilet

68 German Toilet Organization e.V., n.d..
69 Bayerisches Landesamt für Wasserwirtschaft, 2000, p. 5.

### 3.1.4 Treatment

The inputs and outputs of the sewage system end up in waste water treatment plants. Waste water treatment became urgently important at the end of the 19th century in order to protect human health and to prevent epidemics. First technical measures included systematic wastewater drainages and mechanical treatment to reduce the transmission of pathogens into surface and drinking water. Since then, technical wastewater treatment has been continuously developed.[70] Its main function is to prevent the spreading of waterborne diseases, provide hygiene, ensure the quality of drinking water and to protect the environment from hazardous residues and water bodies from eutrophication. To this day, the treatment of municipal waste water begins with its disposal, for example at a toilet. Following steps are the collection and discharge via public sewer systems to central treatment plants. In Germany the largest part of sewers are mixed sewers, collecting storm and rain water together with waste water. Conventional treatment plants process the waste water in three treatment stages: mechanical, biological and chemical treatment. The mechanical treatment is a physical process in which settleable substances like fecal matter, plant residues, toilet paper, girt etc. are separated from the from the wastewater through screening. The result of the primary treatment is primary sludge. In the second stage, waste water is biologically treated trough nitrification and denitrification. Tertiary treatment involves the use of chemicals and includes filtration, precipitation, flocculation or neutralization to remove nutrients like nitrogen and phosphorus.[71] Conventional treatment plants do not sufficiently reduce micropollutants from anthropogenic origin like cosmetics, pharmaceuticals, hormones and nanomaterials. The introduction of a fourth treatment stage can therefore contribute to a reduction of micropollutants in surface water.[72] At the end of the treatment process the effluent water is discharged into a body of water. The remaining sludges are then disposed or used.

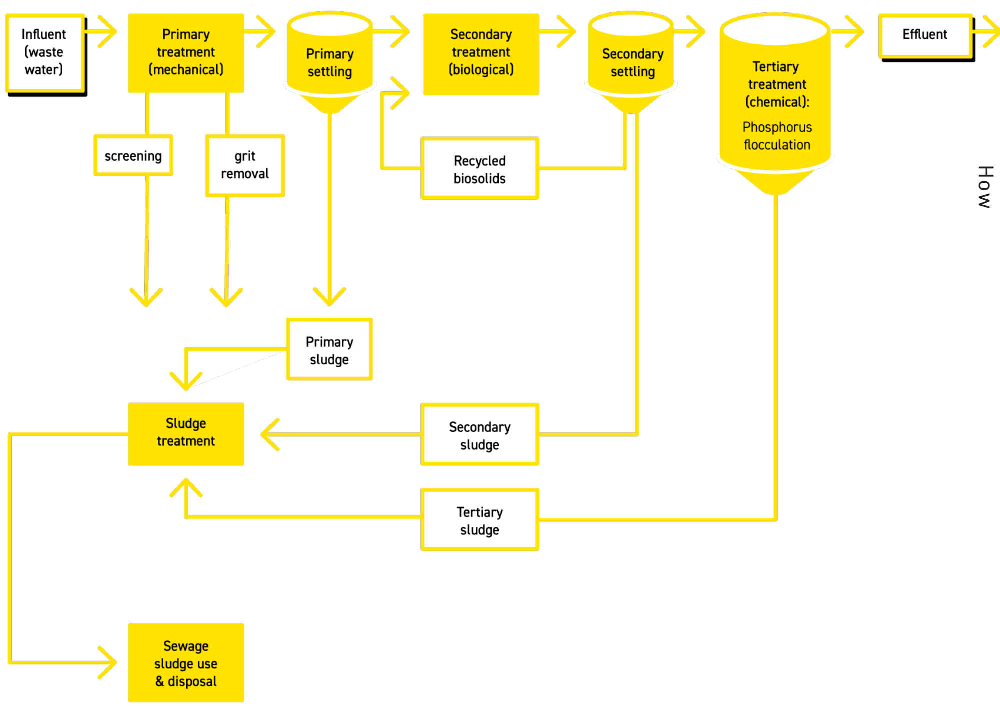


Fig. 10: Waste Water Treatment System

70 Bundesministerium für Umwelt and Umweltbundesamt, 2017, p. 66.

71 Ibid. p.66

72 Ibid., p. 168.

### 3.1.5 Use and Disposal

There are different ways of using and disposing sewage sludge and the nutrients it contains. As outlined before the agricultural use of sewage sludge, sludge mixtures and composts amounted to 16,38% of all generated sludge in 2020. Due to the revision of the sewage sludge regulation, the agricultural application will be gradually restricted. Landfilling used to be another disposal option which is prohibited since June 2005.[73] The largest amount of sewage sludge, 76,7% in 2020, is disposed through mono- or co-incineration.[74] Before incineration the sludge is dewatered and dried to reduce its volume, to improve the transportability and to increase its thermal energy efficiency.[75] Incineration varies depending on whether the sludge is solely combusted (mono incineration) or co-combusted. Furthermore, alternative thermal and chemical-physical processes treatment options like pyrolysis, wet oxidation or hydrothermal carbonization are being developed. However, most of these treatment processes are still in the development stage.[76] Mono- or co-incineration takes place in different plants like coal-burning power plants, cement or waste incineration plants. During the incineration process, phosphorus is incorporated into the ashes. In advanced technological facilities the phosphorus from mono-incinerated sewage sludge ashes can be re-dissolved.[77] If the total amount of sewage sludge produced in Germany were to be exclusively mono incinerated, followed by phosphorus recovery, around 40% of the current agricultural consumption of mineral phosphorus could be replaced.[78] However only 5% of the ashes are used as fertilizers. About one third is used for landscaping and road building. Most ashes (37%) are used for mining backfill. The remaining third ends up ends on landfills.[79] The removal of phosphorus from the global cycle through sewage sludge combustion requires a revision of the recycling process, which should allow for an intervention prior to waste water treatment and incineration. Hence it is worth taking a look at the beginning of a sanitation system and alternative user interfaces that do not require water for disposing excreta.

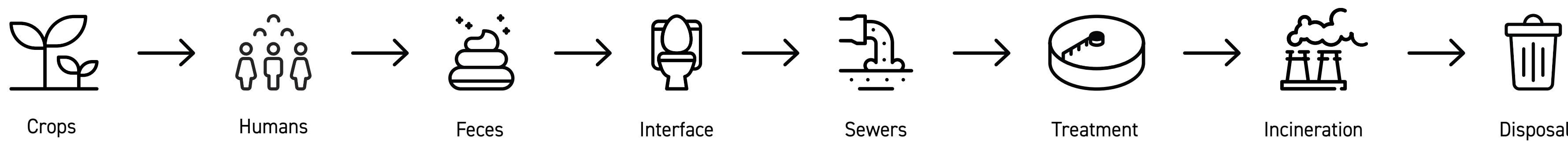


Fig. 11: Linear Flow

73 Roskosch and Heidecke, 2018, p. 59.
74 Statista, Klärschlammentsorgung in Deutschland, 2020.
75 Roskosch and Heidecke, 2018, p. 31.
76 Ibid., p. 38.

77 Ibid. p. 41.
78 Ibid. p. 49.
79 Roskosch and Heidecke, 2018, p. 55.

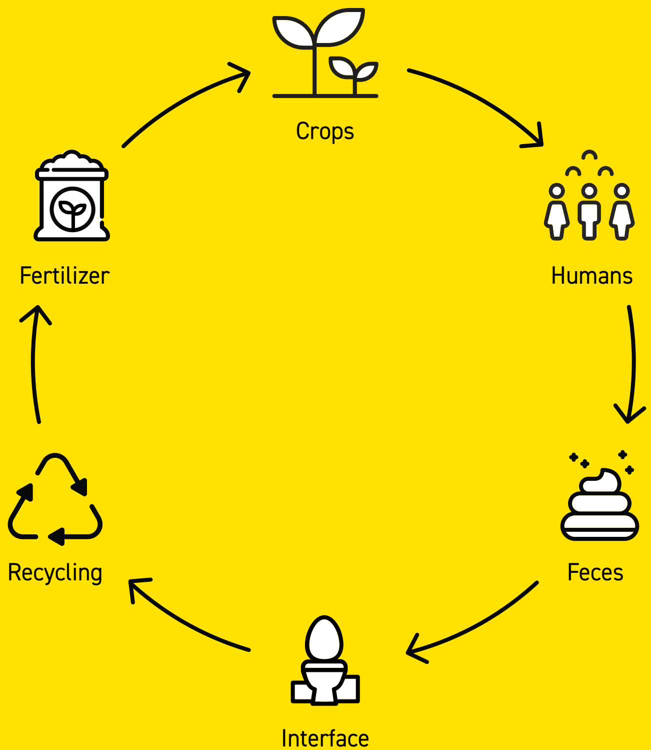


Fig. 12: Circular Flow





# 3.2 Innovative Sanitation Systems

### 3.2.1 Current regulations

The legal basis for the disposal of sewage sludge is the Closed Substance Cycle Waste Management Act (Kreislaufwirtschaftsgesetz - KrWG). Further specifications on the use of sewage sludge can be found in the sewage sludge regulation (Klärschlammverordnung - AbfKlärV) which supplements the KrWG. The AbfKlärV governs the application and incorporation of sewage sludge, sewage sludge mixtures and sewage sludge compost on agricultural, horticultural or forestry land.[80] It was renewed in 2017 and introduces the obligation to recycle phosphorus from sewage sludge or the ash resulting from its thermal treatment. From 2029 onwards wastewater treatment plants with a size or minimum population equivalent of 100.000 people need to recover at least 50 % of the phosphorus contained in the dry matter from the sewage sludge itself or recover at least 80% of the phosphorus contained in the sewage sludge incineration ashes. For treatment plants with a population equivalent of upwards of 50.000 people, the regulation will apply from 2032 onwards, which is 15 years after the introduction of the regulation.[81] It also defines the use of sewage sludge on fields. According to § 15 it prohibits the of raw usage of sludge, mixed sludge and sewage sludge compost on grassland, crop land cultivated for forage, land used to grow corn, acreage for sugar beets, cultivated area for vegetables, fruit or hops, house gardens, kitchen gardens or allotment gardens or forestry land. With an authorization of the responsible agricultural authorities a usage of sewage

80 Bundesministerium der Justiz, 2017.
81 Roskosch and Heidecke, 2018, p. 4.

sludge on crop fields can be permitted.[82] Sewage sludge from smaller treatment plants with a smaller population equivalent than 50.000 can still be applied. Furthermore, the AbfKlärV introduces the obligation to test sewage sludge for disease control and phyto hygiene. It defines sampling criteria for heavy metals as well as phosphorus and nitrogen, among others, in order to ensure the protection of humans and the environment.[83]

Sewage sludge is currently the only way to make use of the nutrients contained in human feces and urine. Separately collected human feces and urine are currently not listed as potential sources for fertilizers in the respective tables of annex 2 of the DüMV. In 2018 the Federal Environment Office (Umweltbundesamt) issued a statement outlining a specific ban on the use of compost from human feces referencing to the current fertilizer and waste regulations. Furthermore, the notice argues that there are major doubts as to whether the recycling process can be carried out without harm. "Ferner ist eine Verwertung schadlos, wenn sie gemäß § 7 Absatz 3 Satz 3 KrWG nach Art der Beschaffenheit der Abfälle, dem Ausmaß der Verunreinigung und der Art der Verwertung Beeinträchtigungen des Wohls der Allgemeinheit nicht zu erwarten sind, insbesondere keine Schadstoffanreicherung im Wertstoffkreislauf erfolgt. An einer schadlosen Verwertungsmöglichkeit bestehen erhebliche Zweifel." The statement issued by the Federal Environment Office was passed on to several local authorities making it more difficult for providers of alternative sanitary systems to apply for individual case permissions.[84] Various providers in Germany nevertheless collect feces and recycle them in composting plants or in approved research trials according to the DüMV (see pp. 21). The collected urine is mostly disposed in sewage treatment plants. As an additional challenge, separately collected feces and urine do not have a specific waste classification code according to the Waste Catalogue Regulation (Abfallverzeichnis-Verordnung - AVV). The AVV defines the classification of waste according to its hazardousness.[85] Other codes are currently used for transporting and treating the materials, such as 19 08 05 (sludges from the treatment of municipal wastewater), 20 02 01 (biodegradable waste) or 20 03 04 (sewage sludge).[86] According to the German Association for Water Management (DWA) the use of urine and feces is not yet covered by the existing legal regulations which makes their agricultural use for example quite difficult.[87]

82 Bundesministerium der Justiz, AbfKlärV § 15.
83 Ibid. § 5.
84 Interview Goldeimer
85 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2001, p. 1.
86 Ibid, p. 29.
87 DWA 2014, p. 24.

**DIN SPEC 91421**

Due to the lack of regulations and standards for the use of recycled fertilizer products from separately collected urine and feces, a group of scientists developed the DIN SPEC 91421 „Qualitätssicherung von Recycling-produkten aus Trockentoiletten zur Anwendung im Gartenbau". The conducted qualitative risk analysis defines specific requirements for characteristics and properties of recycled products to be used as fertilizers in horticulture. These are divided in four categories: epidemic and phyto hygienic conditions, pollutants and the applicability for horticulture.[88] Based on the risk analysis, specific quality management requirements are defined. The DIN SPEC was published in October 2020. It is a pre norm which can be further developed and translated into a DIN-norm. Defining these standards is key to creating a legal framework in which quality-assured recycling of human feces and urine is regulated. It is an important step towards the amendment of the fertilizer regulation (DüMV). With reference to the DIN-Spec the research project *zirkulierBAR* issued a statement in January 2022, on the EU legislative act 2019/1009 which supports the extension of fertilizers to include organic and recycled raw materials and the associated recycling of nutrients. Therein the research project recommends the admission of recycled fertilizers from human feces and human urine.[89] Besides the legal challenges, there is also the need for alternative sanitation systems in order to successfully recycle valuable nutrients from human waste.

88 Krause et al., 2020, p. 4.
89 *zirkulierBAR*: REGION.innovativ, 2022.





### 3.2.2 Interfaces

**Dry toilets**

In comparison to flush toilets, dry toilets do not use water and therefore represent an innovative sanitary system. There are different variations of dry toilets with interfaces for sitting or squatting. Examples can be found in the form of urine diverting dry toilets, compost toilets, pit latrines and container-based solutions. Urine diversion refers to technologies that separately collect urine and prevent the mixing with feces.[90] Urinals can therefore also be classified as diverting interfaces. Urine diverting toilets mostly have a divider to prevent the mixing with feces or use a drainage system in the collecting container, that diverts the urine. By separating the urine, odor formation as well as ammonia outgasing are reduced.

In regular dry toilets, the collected feces are covered and dried with materials like lime, ash or sawdust, which also reduces odors. In container-based solutions the material is collected in sealable and removable containers, that can be stored and transported to treatment facilities.[91] Especially container-based systems therefore provide a solution for countries and populations that do not have access to a sanitation infrastructure, as well as for contexts without access to sewage systems. In Haiti for example less than 1% of the country's excreta are safely managed. The non-profit research and development organization Soil provides a container-based sanitation service with excreta collection

90 Tilley et al., 2014, p. 44.
91 Ibid., p. 46.

for a monthly fee.[92] In Germany dry toilets are already commonly used in contexts like allotment gardens, on festivals or in campervans. Further opportunities for the application of dry toilet solutions can be found in contexts where a direct connection to the sewage system is not given and an intermediate process for discharging excreta is required. The transportation sector (trains, buses, airplanes and boats) therefore constitutes a further opportunity for the use of dry toilets.

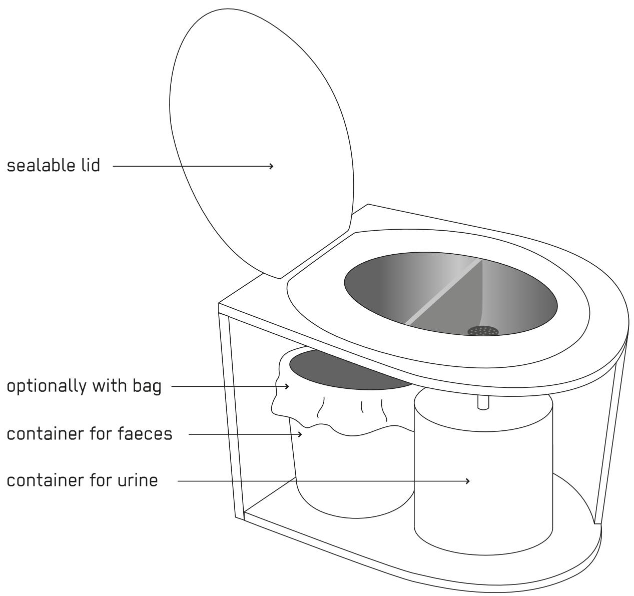


Fig. 13: Container based Dry Toilet

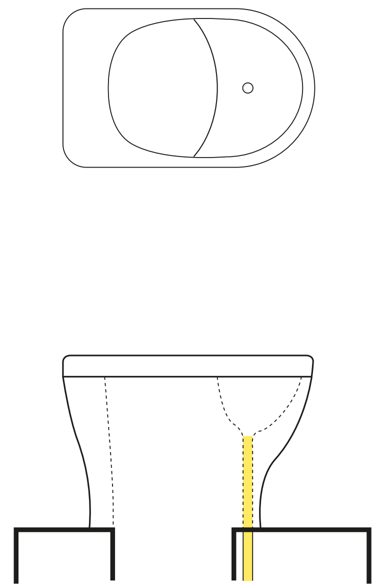

Fig. 14: Dry Toilet Interface

92 Soil, n.d..

### 3.2.3 Use and disposal

The use and disposal of the separately collected materials of dry toilets varies, depending on the context and location of the toilets.

**Allotment gardens**
In allotment gardens gardeners most commonly dispose the collected feces in the residual waste and discharge the urine into domestic toilets. Alternatively, they may use the separately collected urine in a diluted form as fertilizer. Feces can be treated and used after on-site composting, terra preta production, cold rotting or vermicomposting. These decentralized disposal techniques require the end-users to actively handle their feces and urine by emptying the containers, composting and finally applying the compost.[93]

**Camping**
Manufacturers of dry toilets for camping vehicles recommend the disposal of collected materials on the user's property, if available. If this is not possible, feces can be disposed through the household waste and urine through toilets that are connected to the sewer system or at disposal facilities for camping vehicles.[94]

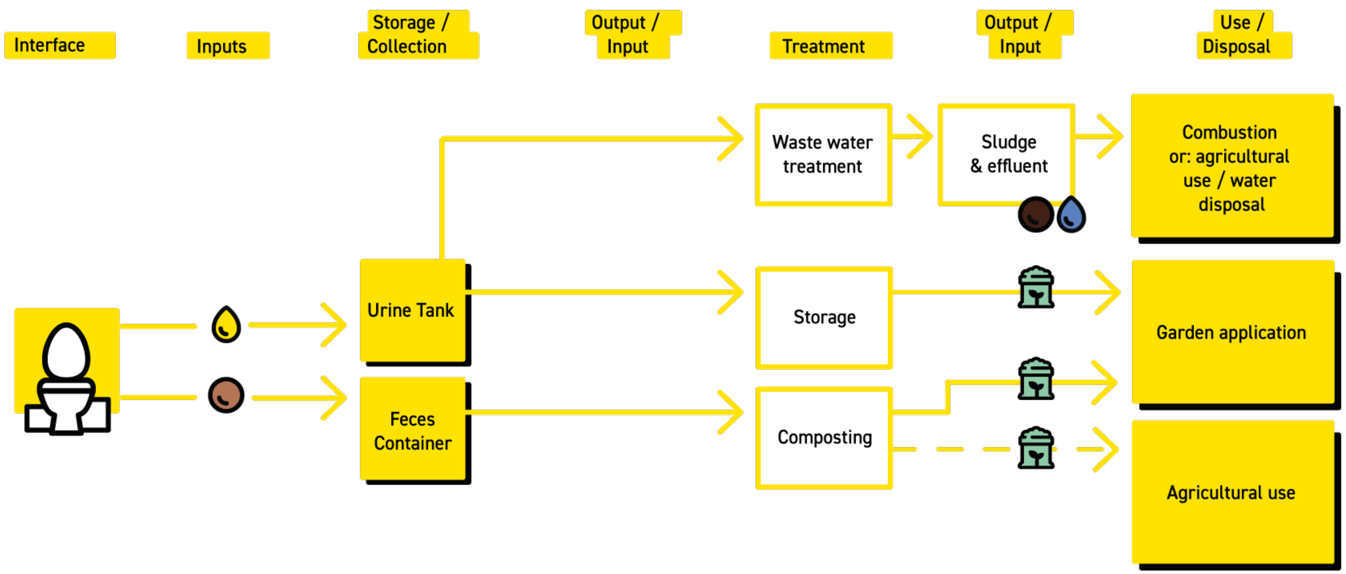


Fig. 15: Systematic Visualization: Dry toilet

93 Deutsche Bundesstiftung Umwelt, 2012, p. 3.
94 Trobolo, n.d..

How

**Festivals and public toilets**
As outlined above, commercially collected urine and feces from festivals or public toilets are currently not legally defined as fertilizer materials. Most providers therefore dispose the collected urine into the sewage system. In order to make use of the collected feces providers need to seek permission for research and trail applications for composting and applying the collected material in order to use and recycle valuable nutrients.

The following map shows dry toilet providers in German speaking countries, that either rent or sell dry toilets. The context in which these toilets are being used are mainly events like festivals or the public space.

Fig. 16: Dry Toilet Providers in Germany

### 3.2.4 Innovative treatment

In order to recycle nutrients from the separately collected materials, innovative solutions are needed. The following chapter focuses on two approaches in order to give an overview of the current state of the art within the field of sanitary nutrient recovery. The two given examples of *Finizio* and *Vuna* showcase processes, that tackle recycling in an early stage of the sanitary system by using dry toilets and circumventing the sewage system.

**Feces: Finizio**

*Finizio – Future Sanitation* is a startup located in Eberswalde, which developed a pilot plant for recycling contents from dry toilets together with the *Kreiswerke Barnim* (KWB). *Finizio* commercially collects contents from dry toilets on festivals as well as their public toilets in Eberswalde, in order to produce nutrient rich fertilizer. Many other providers of dry toilets, such as Goldeimer, EcoToiletten Berlin and Klos to nature transport their collected feces to Eberswalde as well, in order to transform them into compost. The company itself also provides dry toilets. Currently mainly feces are being composted, while the separately collected urine is currently disposed into sewage system. The company is planning to extend their portfolio with urine processing.



How

**From shit to H.I.T.**

The process of treating feces begins with hygenisation. The solids are collected in a heat insulated container. Through ventilation pipes at the bottom, air circulates through the substrate. The power consumption of the fan amounts to only 80 watts.  Aerobic microorganisms then begin to decompose the biomass, generating temperatures of up to 70 degrees Celsius. In this way pathogens such as salmonella or E.coli are inactivated. In the following treatment step the decontaminated material is mixed with green waste, clay minerals and plant charcoal. After seven days the mixture is stacked in heaps. Within a controlled environment humification begins. The temperature is kept at 55 to 65 degrees Celsius to ensure that the humifying bacteria do not die. With a turning machine the heaps are being regularly turned to keep the level of oxygen at 5% and the moisture between 55 and 60%.[95]


Fig. 17: Hygienization Container

95 Finizio, Pilotanlage, n.d..

Within 6-8 weeks, high-quality humus complexes, so called H.I.T. (Humusdünger aus Inhalten von Trockentoiletten) are built up. The final step of the process is to sieve the humus.[96] As outlined before, the fertilizer is officially not yet approved for usage. In 2020 *Finizio* together with the Schorfheider Agrar GmbH carried out a first agricultural field test. The humus fertilizer was allowed to be applied for research and testing purposes. The aim of the three-year field trial is to test and prove the effectiveness of the fertilizer as well as its harmlessness.[97]

Fig. 18: Humus Turning

96 Krause, von Hirschhausen et. al., n.d..
97 Finizio, Der erste Feldversuch, n.d..





**Urine: Vuna**

In order to use urine as a safe fertilizer, *Vuna*, a spin-off of EAWAG in Switzerland developed a process for nutrient recycling. For the process urine needs to be collected separately with a suitable toilet interface, a urinal or urine-diverting toilet. The process is divided into three steps. First, the urine needs to be stabilized through biological nitrification. In this process, bacteria oxidise half the ammonia into non-volatile nitrate ($NO_3^-$) and, as the pH drops, the other half is stabilised as non-volatile ammonium ($NH_4^+$).[98] The nitrification bacteria grow on plastic biofilm carriers which are floating in the aerated column of the urine processing plant. In the second step the nitrified urine is purified. Pharmaceuticals and hormones are removed through activated carbon. Finally, the liquid is distilled, and pathogens are removed by heating the solution to 80°C for half an hour. The liquid volume is reduced by removing 97% of water through distillation. The final products of this process are distilled water and the liquid fertilizer *Aurin*[99]. It is a multi-nutrient solution containing primary nutrients such as nitrogen, phosphorus, potassium as well as secondary nutrients like boron, iron and zinc. Aurin fertilizer was approved in Switzerland by the Federal Office for Agriculture in 2018.[100]

98 Etter, Udert and Gounden, 2015, p. 8.
99 Ibid., p. 11.
100 Vuna GmbH, n.d..

# 04 Who

## 4.1 Innovation Ecosystem Barnim

The theoretical foundation for an analysis of the innovation ecosystem in which *Finizio* was able to implement Germany's first pilot plant for recycling feces has been laid out in the previous chapters. The following pages will now take a closer look at the different stakeholders that made the implementation of this project possible, focusing closely on the region Barnim, Eberswalde and its administrative structures. Which stakeholders played an important role in the process of implementing the pilot plant and establishing public dry toilets in Eberswalde? What are – in consequence – the necessary conditions for realizing such innovative projects in municipalities? Which challenges occurred and what can other municipalities learn from this process? The aim of the upcoming chapter is to identify roles, challenges and opportunities that need to be considered for developing an innovative and ecological sanitary system in the public space as a direct service provided to the citizens.

Following these questions, a series of interviews has been conducted with the relevant stakeholders of the ecosystem. To provide a further understanding of the relevant stakeholders involved, they are allocated to their corresponding field of either government, society, science or industry and placed on an ecosystem map. The resulting, so called quadrupel helix model for the stakeholders in Barnim / Eberswalde also includes their relations, as shown on the next page.

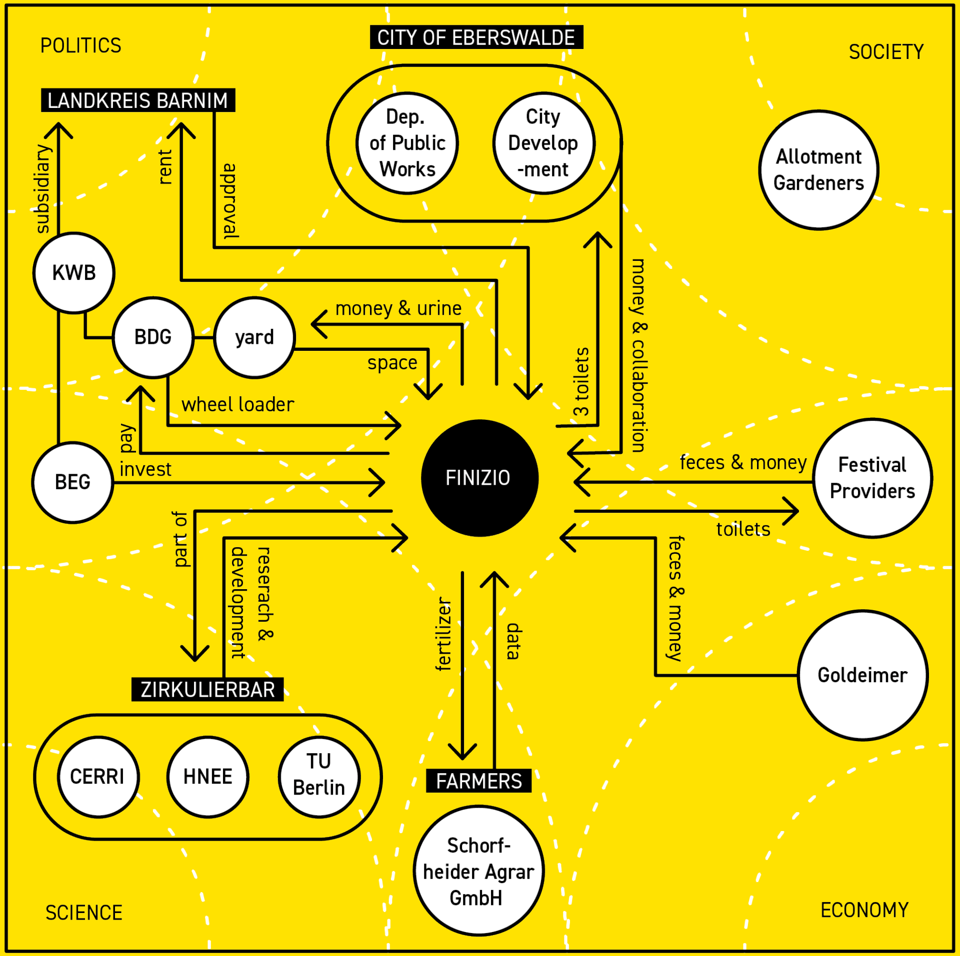


Fig. 19: Quadruple Helix Ecosystem Map

**Finizio**

*Finizio* can be classified as the key stakeholder within the innovation ecosystem. In order to understand how *Finizio* evolved, one needs to take a look back at the beginning. *Finizio* was founded by Florian Augustin, a graduate from the HNEE in April 2019. It evolved from the company Öklo which was originally based in Freiburg. Öklo was a provider of dry toilets and had a collaboration with a composting plant for composting the collected feces. The use of the compost was prohibited by the State Office for the Environment and had to be burned, which was very frustrating for the company. Due to a contact person at the *Kreiswerke Barnim* (KWB), who supported the idea of composting feces, *Finizio* was then founded in Eberswalde. In the beginning, the main focus was to find an area for experimenting with the composting process. With the support of KWB, *Finizio* gained access to the administrative network which permitted and supported the company and its pilot plant.

*Finizio* holds various roles within the ecosystem, being a pioneer within the field of sustainable sanitation and a diver for change by developing innovative dry toilets as well as composting facilities. At the same time, they are a service provider of dry toilets for festivals and for the city of Eberswalde as well as a service provider for composting feces. By conducting field trails for the application of humus fertilizer from contents of dry toilets, *Finizio* operates in between the fields of entrepreneurship and research.

The main challenge for the company is the legal approval for the usage of the humus fertilizer. Further challenges are user acceptance of the toilets as well as education and the use of correct terminology for alternative toilets. The following quotes underline these insights:

“*Finizio* has been in the *Modz* [local newspaper] several times and they regularly call the toilets outhouse [Plumpsklo] and that’s actually kind of absurd because *Finizio* doesn’t want to be compared to outhouses. Many people associate it with a foul-smelling latrine. That’s just not the image we want to convey. You always have to make sure that the right vocabulary is used.”[101]

“In the beginning, the cleaning was also done by *Finizio* in the public toilets. Now a subcontractor does that. Florian Augustin once had a situation where a small child was watching him, because the playground is right next to the public toilet. The child saw him arriving for cleaning the toilet and told his father: ‘Daddy, there’s the yucky man again.’ It’s just really important to talk to people, even on site and at the festivals, and to do a bit of educational work by explaining what happens and why the toilets are not flushed with water.“[102]

101 Interview with former Finizio employee Anna Calmet, translated quote, (22.02.2022).

102 Ibid.



Finizio's roles:

- Pioneer
- Developer
- Provider for dry toilets and composting feces
- Driver for change
- Scientific trail

**Kreiswerke Barnim**

The county of Barnim owns a subsidiary, the *Kreiswerke Barnim* (KWB). The KWB has the goal to promote regional projects related to climate change mitigation. It is strategically implementing projects that tackle sustainable development based on Barnim’s zero-emission strategy. It has two sub-companies, that are important regarding *Finizio*: the Barnimer Energiegesellschaft (BEG) and the Barnimer Dienstleistungsgesellschaft (BDG). The BEG is responsible for project financing and concepts while the BDG is in charge of the waste management service. *Finizio’s* pilot plant is located on a former waste disposal site. The site was designated as a research and development area in the development plan for the city of Eberswalde, which allowed the use of the area for the pilot plant. In order to build the plant, the KWB acted as a networker and promoter. Christian Mehnert, the managing director of the KWB stated: “I was so thrilled by the casualness with which he [Florian Augustin] talked about poop and his idea. My maker heart simply kicked to tackle that project." By providing contacts to the environmental offices responsible for approving the pilot plant, the KWB became a very supportive partner. It turned out, that due to the small amount of material undergoing composting, the local environmental office of Barnim was actually the responsible entity. As they are the legal owner of the KWB, close contacts existed and temporary permit for composting feces was issued. *Finizio* received further hands-on support from the BDG who rented out their wheel loader. Financial support is provided by the BEG, who – as part of the research project *zirkulierBAR* – is investing into the development of an optimized composting shelf.



Regarding challenges for implementing a pilot plant for composting feces, Christian Mehnert pointed out that water authorities are one of the main challenging stakeholders who need to be convinced as they fear to lose a part of their material flow and therefore their function. In Barnim the department for waste management and water department belong to the same office which has simplified the coordination between the departments and in the end lead to an approval of the pilot plant. According to Mehnert, the key factors that need to be given to successfully implement such a project are people with passion, time, motivation, courage and a high frustration tolerance.

"Such projects are always driven by people who have the courage to tackle them, who don't want to excuse themselves with phrase like: It's not in the law, that's not possible, I'm not responsible for it. You simply need people who have the courage to tackle such things, who also think about the future and who want to change things for a sustainable future."[103]

"You also have to want to do it. You have to invest time in it, and you also have to accept that things will fail and that they won't progress as quickly as you would like."[104]

Kreiswerke Barnim's roles:

- Promoter of sustainable projects
- Networker
- Tool / facility provider
- Investor



**County of Barnim**

As the proprietor of the KWB, the county of Barnim can be classified as an additional supporter. The administration of the county is divided into 12 offices including the Environmental Office and the Office for Sustainable Development, Cadaster and Measurement. In an interview, Dr. Wilhelm Benfer, chief officer of the Office for Sustainable Development, highlighted the successful foundation of the KWB as a subsidiary com-

103 Interview with Christian Mehnert, translated quote, (15.03.22).
104 Ibid.

pany for implementing projects related to sustainability and climate change mitigation. The county administration was responsible for approving the use of the site for the pilot plant and also rents out the property to *Finizio*. The county therefore acts as an enabler, promoter and space provider. Dr. Benfer also emphasized the relevance of individuals who are open to innovation and actively support new ideas. “I think the point is that it is individual people who are important, if they are there, something can be initiated and implemented, if they are not there, nothing can be achieved. This should not be underestimated. […] People willing to try things out, to consciously do things that we have never done before or to do additional things that we have not done before, because we live in a time of fundamental change and we need to question everything in order to prepare ourselves for the future.” Furthermore, he outlined the potential of a creative environment which the HNEE provides, that allows for new projects to emerge.

County of Barnim's roles:

- Authorizer
- Enabler
- Space provider
- Promoter



**City of Eberswalde**

The city of Eberswalde belongs to the county of Barnim in the northeast of the state of Brandenburg. It counted 42.841 inhabitants in 2021 and is home to Barnim’s county administration.[105] The relevant stakeholder of Eberswalde’s city administration is the department of Public Works, as they are responsible for green spaces maintenance, playgrounds, cemeteries, forestry and street cleaning. Eberswalde offers two public toilets and three dry toilets provided by *Finizio*. The city can be classified as an enabling stakeholder who provides *Finizio* with financial recourses and a framework for developing their business, even though it would have been cheaper for the city to use chemical toilets. The city thereby acts out of commitment for sustainability and enables pioneering work in the sanitation sector. Katrin Heidenfelder, the head of the department of Public Works is an enthusiastic supporter of *Finizio*. The close collaboration developed, since *Finizio* made their work accessibly by presenting their pilot plant and the technologies as well as the production of the toilets to the city. “I was allowed to be part of such an action. [*Finizio*] had a day, where you could have a look at everything and how this technology works. I found it terribly interesting because I listened to this lecture and also looked at the technology.” Katrin Heidenfelder stated. The first pilot of a dry toilet was tested on a cemetery. A senior citizens’ association suggested that the city should provide a public toilet for the elderly population. Katrin Heidenfelder was exited to test *Finizios* dry toilet. The first pilot toilet looked similar to a hunting stand and had a staircase. It was accepted and frequently used by Eberswalde’s

105 Stadt Eberswalde, 2022.

citizens. The city required the development of an accessible solution especially for the elderly. Finizo reacted to these requirements and developed an accessible version of a public toilet, a version called Libre. The city then decided to set up two more toilets in a park and along a walking trail. The toilets are very well accepted, but unfortunately the one in the park is also strongly affected by vandalism and was immediately spray painted. Therefore, the city decided to increase the two-week cleaning service to a daily frequency. The costs for *Finizio's* toilets and their service then increased. This is why one of the less frequented toilets needs to be shut down. Katrin Heidenfelder hopes that prices will decrease, once the dry toilets and the composting system is established on the market. Summing up, the greatest challenges the city is facing regarding the public dry toilets are vandalism and financing. "I would very much like to set up more [toilets], but it is financially impossible."[106]

City of Eberswalde's roles:

- Authorizer
- Enabler
- Investor
- Promoter
- Enthusiast
- Pioneer

106 Interview with Katrin Heidenfelder, translated quote (11.02.2022).



**Goldeimer**

Goldeimer is a non-profit company based in Hamburg that promotes the use of dry toilets and offers them on festivals. They closely collaborate with Finizo who treat their collected material. Goldeimer contributes to a paradigm shift in the sanitary field by educating users on site and freeing the sanitation topic from taboos. Enno Schröder, who is responsible for research & development at Goldeimer, emphasizes the potential and success of education, reflected in the positive feedback of festival users who appreciate their service. "People actually camp in the area of our toilets, because they know in the morning there are cleaned toilets. People buy a flat rate bracelet for the whole weekend, to use our toilets. It's an attractive and ecological service that they really appreciate. And it's a great opportunity to educate them on the spot." The main challenge that Goldeimer faces are legal restrictions regarding the use approval of the fertilizer. Further challenges are related to waste logistics and missing waste code numbers for transporting the collected feces. This is why Goldeimer and *Finizio* want to establish a reusable container system for transporting the material.

Goldeimer's roles:

- Service provider
- Pioneer
- Educator

**Schorfheider Agrar GmbH**

The Schorfheider Agrar GmbH carried out a first agricultural field test of recycled humus fertilizer from contents from dry toilets. Together with *Finizio* they collect data to test and prove the effectiveness of the fertilizer as well as its harmlessness.[107]

Schorfheider's roles:

"Consumer"

Researcher

**zirkulierBAR**

The research project *zirkulierBAR* can be classified as a network and driver as it consolidates the relevant stakeholders and provides them with a common platform.

zirkulierBAR's roles:

Driver

Networker

Researcher

107 Finizio, Der erste Feldversuch, n.d..



Based on the findings from the interviews in Barnim / Eberswalde the following challenges and supportive preconditions for implementing a pilot plant can be identified:

Challenges

- Fertilizer approval
- Bureaucratic obstacles like the statement by BUM
- The use of correct terminology regarding dry toilets
- Vandalism
- Education about innovative sanitation
- User acceptance of dry toilets
- Money for public toilets

Preconditions

- Enthusiastic pioneers (*Finizio*)
- Innovative environment due to the Hochschule für Nachhaltige Entwicklung
- High priority / strategic relevance of the sustainably (zero emission strategy)
- Strategic promotion of sustainable projects (KWB)
- Supporters in the city and county administration who promote innovative and sustainable projects
- A close network of open-minded and courageous bureaucrats
- Availability of space for the pilot plant at the recycling facility
- Close cooperation between pioneers and municipal stakeholders

# 4.2 Public Toilet Ecosystem in Cologne

In order to identify the potential for transferring the solution to other municipalities, this chapter explores the public toilet ecosystem and concept of the City of Cologne. What is Cologne's strategy regarding public toilets? Who are the correlating stakeholders in Cologne? Are they aware of the innovation potential within the sanitary field? What is the City's strategy concerning sustainability and climate change mitigation? By comparing stakeholders and structures, existing obstacles and opportunities for an implementation of sustainable sanitation solutions in municipalities will be outlined.



**Why Cologne?**
The City of Cologne declared a climate state of emergency in 2019. The City thereby acknowledges a high priority for climate change mitigation, making it a priority in policy making. Cologne's mayor Henriette Reker therefore established a climate council including various experts from science, business, civil society and the city administration. The committee has six working groups focusing on topics like energy, housing, industry, mobility and logistics, nutrition and consumption as well as communication and participation. The council drives and coordinates change towards a climate neutral Cologne.[108] The city of Cologne also introduced a city strategy called "Kölner Perspektiven 2030+" as a guideline for politics and administration. The strategy is based on five guiding principles, each including five separate goals:

Guiding principle 1: Cologne ensures compact and livable neighborhoods.

Guiding principle 2: Cologne creates space for a dynamic and sustainable economy and for diverse working environments.

Guiding principle 3: Cologne provides for education, equal opportunities and participation.

Guiding principle 4: Cologne strengthens its role as a diverse networked metropolis.

Guiding principle 5: Cologne grows in a climate-friendly and environmentally friendly way and provides for healthy living conditions.[109]



108 Stadt Köln, Klimarat Köln.

109 Stadt Köln, Amt für Stadtentwicklung und Statistik, 2019, p. 3.

In the context of sustainable sanitation goal 5.5 of guiding principle 5 is especially relevant as it states:

Cologne strengthens regional value chains and sustainable material cycles.
# Network production cycles, expand circular economy in the neighborhoods
# Expand regional production and marketing chains
# Strengthen urban recycling services
# Create incentives for waste avoidance
# Promote waste separation and local recycling[110]

The strategy *Kölner Perspektiven 2030+* was approved by Cologne's City Council in December 2021. The implementation and development of key projects and recommendations for actions have begun. The City's goal is to now translate the theoretical concepts from strategy into practice.[111] It provides a solid basis for sustainable development and circular economy. Arguments for innovative and sustainable sanitation systems in Cologne can therefore be derived from the strategy. In addition to the strategic relevance of the subject, there is also an explicit need for public toilets amongst Cologne's citizens. The following quote, sourced from the participatory online platform Senf.koeln, underlines this demand:

"There are too few public toilets in Cologne. I would like to see the number of toilets increase and the social hotspots become more attractive by building toilets. It would also fix the problem of public urination and the garbage it causes. In addition, public toilets should be free regardless of gender, as currently only men are granted free use of the few facilities that already exist. The use of toilets is a basic need and should therefore not be denied to anyone."[112]

**Cologne's toilet concept**
To address this demand, the City of Cologne started to implement a holistic toilet concept in 2013. In comparison to Eberswalde, Cologne counts 1.088.040 inhabitants. Due to its size, Cologne's public toilet concept operates on a larger scale. The offices responsible herefore are the Office for property, measurement and cadaster and the in-house waste management facility (Abfallwirtschaftsbetrieb – AWB). Both are part of the department for environment, climate and property.

A brief historical contextualization gives an insight into how concept was developed. In 1993 the city council of Cologne decided to close all public toilet facilities and signed an advertising rights contract with Cologne's public utility company, the Stadtwerke Köln (SWK). This contract allowed the public utility company to use all public circulation areas in the city for the construction and operation of advertising facilities. The contract also committed the SWB to manage, operate and maintain the public toilets. The rights to operate and manage public toilets was then transferred to the Kölner Außenwerbung (KAW) and JCDecaux Deutschland GmbH (JCDecaux). They were in charge of this task until the contracts were terminated as of December 2014. New contracts were made that

110 Ibid., p. 13.
111 Ibid., p. 13.
112 Senf.koeln, 2020.

separated the operation and management of public toilets from outdoor advertising rights. Therefore, the City administration and the in-house waste management service (Abfallwirtschaftsbetrieb - AWB) introduced a new toilet concept in 2013.[113] The goal of Cologne's toilet concept is to provide a sufficient number of public toilets with special consideration for the needs of people with disabilities. It includes several approaches and toilet facilities:

1. Two "stone-on-stone" facilities (permanently installed toilet facilities in buildings)
2. The installation of 30 accessible City WC facilities
3. "Happy Toilet Cologne" toilets in restaurants and hotels
4. Accessible mobile toilets in green areas (seasonal)
5. Testing the use of urinals
6. Toilets in public buildings (see website: www.toiletten.koeln)

**City WC**

In two interviews, with an employee at AWB and an administrative officer working for the city of Cologne, it was admitted that up to now (2022) only 12 City WC facilities have been build. The main challenge is to find a suitable location for building a City WC which includes the inspection of technical feasibility and the consideration of the following criteria:

113 Stadt Köln, 2013, p. 5.

a. Determine frequencies
b. Consideration of the needs of people with disabilities
c. Consideration of the design advisory board's concerns for harmonic urban design
d. Tourist significance
e. High problem of public urination
f. Traffic infrastructural importance (junction / terminal stop)
g. Overall supply situation including existing offerings
h. Alternatives (in the context of offers from businesses [gastronomy and others], cemeteries, public buildings)
i. Environment (social control)
j. Impressions from sightseeing
k. Pipeline routes for supply and disposal lines [114]


Fig. 20: City WC

114 Stadt Köln, 2013, p. 12.

In order to implement a City WC various administrative stakeholder are involved including the Office for Monument Conservation, the Urban Planning Office, the Office for Landscape Maintenance and Green Spaces, the Construction department and the Design Advisory Board among others. Other relevant stakeholders are politicians, such as district representatives, disability associations and citizens. Due to the multitude of test procedures and requirements it can take up to two years to realize and construct a City WC.[115]

**Mobile toilets**

Compared to the City WC facilities, the implementation of mobile toilets is a lot easier as they do not require a connection to the sewage system. Mobile toilets are mostly seasonally used in green spaces from April until October and often covered in an extra housing made of screen-printing boards to protect them from external influences. According to AWB, 48 mobile toilets will be used in 2022.

The process of setting up a mobile toilet involves fewer stakeholders compared to installing a City WC facility, namely the Office for Landscape Maintenance and Green Spaces and the AWB. Furthermore, fewer criteria need to be considered. These include the accessibility for people with disabilities as well as maintenance requirements like the access for pump vehicles to empty the toilets. Mobile toilets are cleaned on a daily basis and emptied two to three times per week according to the frequency of their usage. The daily cleaning service is carried out by AWB. An external service provider is

115 Ibid., p. 14.






Fig. 21: Mobile Toilet

taking care of emptying and discharging the excreta. The challenges related to public toilets in Cologne differ to the ones in Eberswalde. Besides vandalism and financing, drug use and drug dealing as well bureaucratic processes pose difficulties for the implementation of Cologne's toilet concept.

**Public dry toilets**

Cologne's toilet concept from 2013 included a composting toilet with on-site composting as an innovative alternative to mobile chemical toilets. It was pointed out that the toilet was never built nor tested due to the legal restrictions for using the compost.

However, Studio Quack & Jan Philipp Neuer developed a dry toilet installation called "Gabinetto Galactico" for the CityLeaks Urban Art Festival in 2021. It was located in one of the railway arches in Ehrenfeld and used by the public for the duration of the festival. CityLeaks invited the public to engage in the festival and its architecture in and around the vacant railroad arches and transformed the landscape into an urban garden area. The festival was framed under the title "Simul et Singulis" and created a three-month long real laboratory of urban art and participatory urban research. It explored the potentials of public space, its streets, green and open spaces and addressing topics such as climate justice, urban resilience, and densification.[116] The toilet concept contributed to the reflection about circular economy by making it tangible.

"Gabinetto Galactico" claimed to compost the collected material and to use the fertilizer afterwards. In an interview, Konstantin Hehl, who is working for the CityLeaks festival, stated that the collected urine had to be disposed in a wastewater treatment plant. Regarding the feces he admitted: "We don't know what to do with the shit now. It has been laying here for almost a year now. We tried to convince the city to provide us with a site for composting the material. The parks and gardens department liked the idea of composting and closing the nutrient cycle. In the end we couldn't get a site for composting though."[117] Regarding the usage and acceptance, he noted that the toilet was very much appreciated and frequently used by the public and the festival visitors.

This project showcases that the City of Cologne and the responsible stakeholders are not up to date regarding the latest research in the field of collecting and treating contents from dry toilets in order to close the nutrient cycle.

116 CityLeaks Urban Art Festival, 2021.
117 Interview with Konstantin Hehl, (05.02.2022).





Fig. 22: City Leaks Festival Dry Toilet Outside

Fig. 23: City Leaks Festival Dry Toilet

**Stakeholders in Cologne**

The following pages therefore focus on authoritative stakeholders in Cologne's administration that need to be involved in the process of testing and piloting the use of public dry toilets and the recycling of the collected contents. Based on and compared to the structures in Barnim, the following corresponding administrative stakeholders can be identified. Regarding the use of public dry toilets and composting feces the following statements highlight challenges and skepticism as well as interest of the relevant stakeholders.

Department for environment, climate and property
- Coordination office for climate change mitigation
- Environmental Office
- Office for public green spaces and landscape management
- Office for Property, Measurement and Cadaster
- In-house waste management facility (Abfallwirtschaftsbetrieb - AWB)

Mayors department
- Innovation office

**Department for environment, climate and property**
In a conversation with one of the departmental officers of the department for environment, climate and property, the idea of using dry toilets to compost feces and recover nutrients was positively acknowledged. Due to internal reorganization of the department further conversations have not yet taken place. The mindset and general openness towards the project seems to be given, which offers a potential for further cooperation.[118]

Department for environment, climate and property's Roles:

- Authorizer
- Potential Enabler
- Potential Enthusiast

**Coordination office for climate change mitigation**
The head of the coordination office for climate change mitigation was not yet willing to talk about the topic of sustainable sanitation, as it does not belong to the office's responsibilities, according to the head of the office. Therefore, a conversation did not take place, but the inquiry will be forwarded to the responsible department.[119] The coordination office for climate change mitigation offers a funding program which promotes sustainable social and technological innovations and could therefore be an important stakeholder for providing financial resources.[120]

Roles:

- Potential resource provider
- Potential Enabler

118 cf. call Miriam von der Burg
119 cf. E-mail A. Bauer
120 Stadt Köln, Förderprogramm SmartCity Cologne GO, n.d..

Who

**Environmental Office & Office for public green spaces and landscape management**

These offices were not part of the research.

**AWB**

The interview partner at AWB mentioned several concerns regarding the use of public dry toilets. The legal approval of the fertilizer was the main concern: “We don’t do anything that is not legal or covered by law.” Furthermore, he stated: “I’m exaggerating now, so if we had such a small bucket somewhere, 10 liters and we have to get the feces out every time, but at the Aachener Weiher where there is a volume of, let’s say, 1000 liters a day, it’s far from practical. Therefore, it is necessary to think on a different scale. In Cologne, we have a very, very high waste volume.” Other concerns referred to malodor that could occur and the overall ecological footprint of a dry toilet service system including emissions for transpiration that need to be considered. Technical considerations that were pointed out included the examination for using an underground tank for urine collection. “I have been in this business for a long time, so I already have some practical experience and am not fundamentally skeptical or anything like that, so that’s not important to me. I would like to try things out as well. They have to be practical and they have to be feasible for our business tough. […] Every extra toilet offering will certainly be appreciated.” He concluded with the statement: “[...] I still have a few years ahead of me in my professional life, and I would like to contribute to shaping them.”[121]

121 cf. interview employee at AWB



Roles:

Potential Pioneer

Potential Developer

Potential Service Provider

**Innovation office**

In an interview Maik Dick, head of Cologne’s administrative innovation office, supported the idea of a project for recycling excreta from dry toilets. “I think this project has potential, as it is a hands-on project and a direct service for our citizens. We, as the innovation office, could support such a project on a strategic and process level. We cannot be our own commissioners though and therefore need to find a client, for example the AWB.”[122]

Roles:

Potential Enabler

Potential Coordinator

Enthusiast

122 cf. call Maik Dick

# 05 Now what

## Conclusion

In this research proposal, the need for and the potentials of innovative sanitary systems have been discussed. The use of dry toilets, that separately collect feces and urine, for example allow for the efficient recycling of the contained nutrients, like phosphorus and nitrogen. They can then be used to produce humus and liquid multi fertilizer, which addresses several environmental challenges.

Phosphorus is a non-renewable raw material mined for fertilizer production from limited rock phosphate deposits and essential for all living organisms. Besides political conflicts the quality of mined raw phosphate decreases due to the contamination with heavy metals like cadmium and uranium which pose risks to humans and the environment. Humans as well as animals assimilate nutrients like phosphorus and nitrogen through the consumption of plants, which are then excreted. The largest amount of the remaining sewage sludge from treated excreta is disposed through incineration, because a direct application on agricultural fields is continuously restricted. Thus, phosphorus is removed from the global cycle. Germany therefore introduced the obligation to recycle phosphorus from sewage sludge or the ash resulting from its thermal treatment in 2017, which is energy consuming and requires advanced technological facilities. Hence dry toilets offer an alternative interface and treatment process to the linear, water-based sanitary system. Dry toilets enable waterless excreta disposal and thereby offer a great potential for saving water. Energy consuming wastewater treatment and nutrient recovery from sewage sludge and ashes are not required when urine and feces are separately collected. Hygenization and thermal composting of feces enable the production of a high-quality fertilizer which fixates $CO_2$ and contributes to soil protection trough humus formation. Composting feces and recycling urine can thereby locally close nutrient cycles. Due to the missing legal regulations these recycling processes can currently only take place in a research and trial context. The research project *zirkulierBAR* aims to change this by continuing to develop standards like the DIN SPEC 91421 for the use of recycled fertilizer products and a blueprint for a treatment plant, that can be adopted by other municipalities.

The analysis of the innovation ecosystem in Barnim / Eberswalde showed that several preconditions need to be given for introducing a public dry toilet sanitation system. These include an innovative environment and the presence of enthusiastic pioneers who develop and provide dry toilets. Moreover, a strategic promotion of sustainable projects and a network of courageous, open-minded and motivated bureaucrats are essential factors. On the one hand bureaucratic structures can pose obstacles for innovation, while on the other hand a collaboration between pioneers and permitting administrative entities is a promising recipe for innovation.

Based on the investigation of Cologne's administrative public toilet ecosystem, advantageous preconditions for piloting a dry toilet sanitation system can be identified. The City of Cologne acknowledged the high priority of climate change mitigation by declaring a climate state of emergency and introducing the city strategy *Kölner Perspektiven 2030+*. It defines goals to strengthen urban recycling services and to expand circular economy. The strategy therefore provides a framework for developing and testing an innovative and sustainable public sanitation system in Cologne. Furthermore, Cologne's ecosystem covers many of the roles and preconditions that were given in Barnim / Eberswalde, where the first pilot plant for composting feces was build. Various departments and interested bureaucrats are open to the idea of testing public dry toilets including the Department for environment, climate and property, the Office for Waste Management (AWB) and the Innovation office.

Challenges regarding the use of dry toilets that need to be considered are, besides financing and vandalism, mainly user acceptance and education. These challenges form the starting point for the following master thesis. What kind of information material and education formats do stakeholders need to actively engage in piloting a sustainable sanitation solution in municipalities? How can they move from passive to active acceptance and involvement regarding the use of dry toilets and recycled fertilizers? The master thesis can develop in two directions. One the one hand the design of a user-centered dry toilet interface and treatment system could be helpful to make the concept tangible. Thereby skepticism regarding malodors and construction requirements could be tackled. This direction requires further research in the field of user needs and behavior in public toilets as well as an exploration of the current cleaning, transportation and treatment processes of mobile toilets. On the other hand, communication tools and formats for municipal stakeholders could be developed as a means to inform about the topic. A sub-project of *zirkulierBAR* aims to design a simulation game in order to enable stakeholders to experience the benefits of sanitary change in a playful way. A potential collaboration with the project team is currently being discussed.

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Bibliography

## List of Figures



All custom graphics were designed by Anastasia Bondar and illustrated by Pia-Marie Stute.



Bibliography

# Declaration of Authorship

Hereby, I declare that I have composed the presented paper independently on my own and without any other resources than the ones indicated. All thoughts taken directly or indirectly from external sources are properly denoted as such.

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