How can ecological sanitation become a feasible answer to improving sustainable waste management in Norway?

By:
Daan Meylemans

Supervisor:
Kristin Støren Wigum
Petter Jenssen, PhD

Master's Programme
Product Design Department
Faculty of Technology, Art and Design

OSLOMET

22 May 2023

Abstract

This research study investigates "How ecological sanitation can become a feasible answer to improve sustainable waste management in Norway?". Through a holistic systemic analysis, the entire sanitation system in Norway has been examined thoroughly. Even indirectly related systems have been included in the study: agriculture, economy, legislation, politics, culture, habits, behavior, consumption, pollution, water treatment, waste treatment, and the environment have all been studied to investigate where improvement is possible and whether a more ecological sanitation alternative can provide an answer.

Acknowledgment

I am grateful for the opportunity to have studied at Oslomet University and doing research about a topic I am truly passionate about.
First and foremost, I would like to thank Professor Petter D. Jenssen for his professional help and for providing me with great tips and academic articles that were imperative to the success of this Thesis.
Secondly, I would like to thank my supervisor Kristin Støren Wigum for providing critical feedback and helping me with getting in contact with the right people.
Thirdly,I want to thank my family for providing support, tips, sharing relevant information and critical feedback.
Lastly I want to thank all the people that participated in interviews and who's knowledge has elevated this project greatly. Without these people this project wouldn't have had the same value.

Glossary

- **Sludge:** from municipalities (often called sewage sludge) is a byproduct of wastewater treatment. It is normally a mix of organic matter from human waste, food waste particles, microorganisms, trace chemicals and inorganic solids from products and medicine we use, together with water bound to these materials.
- **Centralized waste management system:** is a large-scale sewage pipe system that transports human waste to a central waste treatment plant that treats the waste for an expansive municipal or regional service area.
- **Decentralized waste management system:** is a smaller waste treatment system that treats human waste at the source for a localized area.
- **Eco sanitation:** Form of recycling; the use and reuse of nutrients through means of composting human excreta and using it as fertilizer creates an ecological loop
- **Excreta/Feces/Human Waste:** waste matter discharged from the body, especially feces and urine.
- **Stormwater:** is water that originates from heavy precipitation and meltwater from hail and snow. Sewage systems have a pressure release valve that sends excess wastewater into rivers and seas during a heavy rain event.

- **Surface water:** is any body of water above ground, including streams, rivers, lakes, wetlands, reservoirs, and creeks.
- **Gray water:** the relatively clean waste water from baths, sinks, washing machines, and other kitchen appliances.
- **Black water:** is the wastewater from bathrooms and toilets that contains fecal matter and urine.
- **Fresh water/Clean water:** water from springs, wells, purified water, city water, rain water.
- **Humified:** plant remains that are converted into humus.
- **Defecation:** discharged feces from the body.
- **Humanure:** solid waste from the human body which is later reused as compost or manure.
- **Eutrophication:** excessive richness of nutrients in a body of water, frequently due to run-off from the land, which causes a dense growth of plant life.
- **Effluent:** liquid waste or sewage discharged into a river or the sea.
- **Aeration:** the introduction of air into a liquid or material.
- **Mycorrhizae:** a fungus which grows in association with the roots of a plant in a symbiotic or mildly pathogenic relationship.

Table of Contents

Title Page **1**
Abstract **1**
Acknowledgment **1**
Glossary **1**
Table of Contents **3**
Introduction **7**
Research Question 7
Personal Motivation 7
Purpose of the study 8
Theory & Methods 9
History of Toilets **10**
Insights gained from the History of Toilets 13
Ecological Sanitation **14**
Dry Toilets **15**
Vacuum Toilet System 17
What is a Vacuum Toilet? 17
Advantages & Limitations 17
Cinderella Incinerating Toilet System 19
About Cinderella 19
What is an Incinerating Toilet? 19
Application 20
Function of the Cinderella Incinerating Toilet 20
Cinderella Incinerating Toilet Process 20
Advantages & Limitations 21
Installation of the Cinderella Incinerating Toilet 21
Diverting Compost Toilet System 22
What is a Diverting Compost Toilet? 22
Application 22
Advantages & Limitations 22
Future of Dry Toilets **24**
Waste Treatment Systems **25**
Centralized Waste Treatment System 25
Advantages & Limitations 26
Decentralized Waste Treatment System 26
Advantages & Limitations 26
Klaro Wastewater Treatment System 27
Klaro Wastewater Treatment Process 27
Phase1: Charging 27
Phase2: Aeration 27

Phase3: Rest Phase 28
Phase4: Clear Water Extraction 28
Field Trip 28
Safety 29
How to integrate a sanitary system? 29
One Health 30
Areas of Opportunity 31
Fresh Water Supply 31
Water Consumption 33
Consumer 33
Flush Toilet 34
Foreign objects 35
Industry & Hospitals 35
Black Water 35
Aging Sewage Pipelines 35
Monoculture 36
History of Agriculture 37
Hunter Gatherer Culture 37
Start of Agriculture 37
Invention Disc & Plow 37
Mechanization of Agriculture 37
Chemical Revolution 37
Insights gained from the History of Agriculture 37
Stocks & Flows Map 38
Unsustainable System 38
Technology 39
Subsidies 39
Purpose 39
Monoculture Processor Map 40
Deforestation 40
Tilling 40
Growing 40
Crops 40
Pests 41
Fertilizer 41
Harvest 41
Soil Degradation 41
Consumer 41
Wastewater Treatment Plant 42
Sludge 43
Wastewater Treatment Future Challenges 43

Marine Life 43
Economy 44
Resources 44
Investments 44
Chemicals 44
Electricity 45
Infrastructure 45
Legislation 46
Legislation Limitations 47
Key Barriers to Dry Toilet System Acceptance 48
Overcome Mental Hurdles 49
Pilot Project Examples 49
Solutions 50
Mindset 50
Function or Purpose 51
Interconnections, Relationships & Information Flow 52
Elements 53
Regenerative Agriculture 53
Tree 54
Livestock 54
Grass 54
Pollinators 54
Replenish Topsoil 54
No-Till System 54
Crops 54
Crop Variety 55
Harvest 55
Cover Crops 55
Prescribed Grazing 55
CSA 55
Dry Toilet 55
Compost 56
Water 56
Sanitation 56
Decentralized 57
Urban 57
Single Family Home 57
Centralized 57
Urban 57
Single Family Home 57
Waste Treatment 57

Municipal Composting Facility 57
Compost Collection 57
Tumbler 57
Shredding 57
Pasteurization 58
Aeration and Watering 58
Curing Stage 58
Harness Energy 58
Compost Distribution 58
Compost and the Environment 58
Household On-site Waste Treatment 59
Pretreatment 59
Maintreatment 59
Post Treatment 59
Conclusion 59
Recommendations 59
References 62

Introduction

Research Question

How can ecological sanitation become a feasible answer to improving sustainable waste management in Norway?

The original research question was “How can eco-sanitation become a feasible answer to safeguard Norway’s access to sustainable sanitation?”. Due to more knowledge I changed the research question to “How can ecological sanitation become a feasible answer to improving sustainable waste management in Norway?” because the thesis covers a variety of toilet systems but also the overarching waste management system. As Norway has achieved to provide clean water and adequate wastewater management to the majority of the population I thought the word “safeguard” was misplaced and I replaced it with “improve” to indicate that although Norway is already a global frontrunner when it comes to sanitation there is always room for improvement and innovation.

Personal Motivation

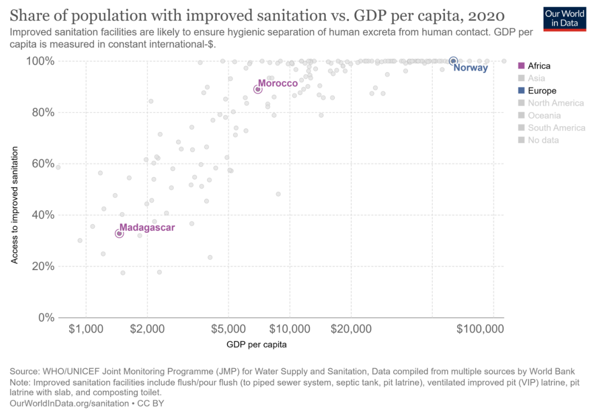
During the summer of 2022, Luxembourg, my country of birth, experienced a drought of eight weeks. Due to the drought my household had to switch to municipal water as our rainwater tank quickly emptied which we use for flushing the toilet and cleaning clothes. To make my household less dependable on municipal water during extended periods of drought I made a compost toilet. During personal use I got to experience the benefits of this sanitation system.

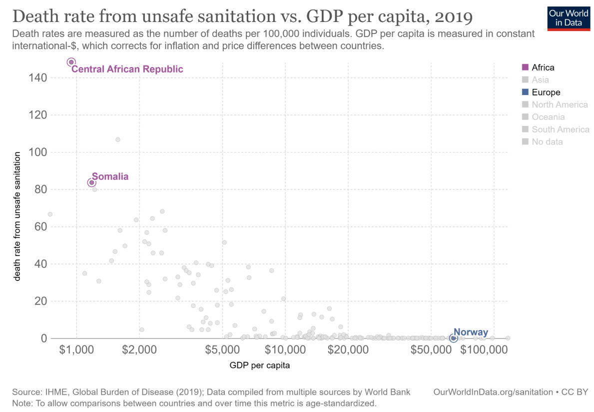
I quickly realized that Norway could also benefit from ecological sanitation as unusual little snowfall and precipitation during the summer of 2022 caused low water levels in the Nordmarka reservoirs despite all the efforts asked from citizens to save water by Oslo municipality (Oslo Municipality, 2022).
Replacing flush toilets with an ecologic sanitation alternative would enable Norwegians to save on their water bill, and all the downstream benefits including lowering their water consumption and not creating polluted water that must be treated.

But could a whole city switch to ecological sanitation toilets?

Purpose of the study

Adequate water, hygiene and safely managed sanitation is detrimental for a healthy population. Poor sanitation reduces human well-being, social and economic development (World Health Organization, 2022). Unsafe sanitation is responsible for 775,000 deaths worldwide annually and is one of the world’s largest health and environmental problems particularly for the poorest in the world. There is a strong relationship; death rates from unsafe sanitation decline as countries get richer and access to improved sanitation increases as countries get richer (Ritchie & Roser, 2021).





As the 6th richest country in the world, Norway's share of annual deaths attributed to unsafe sanitation is negligible (Ritchie & Roser, 2021) as 99.2% of the population is connected to municipal waterworks and 86% of the population is connected to municipal wastewater facilities supplying hygienically safe drinking water and wastewater treatment (Statistics Norway, 2022).

Despite the abundance of freshwater Norway has access to, water is still a precious, finite resource. There is a limit to how many people it can provide for, and using too much of it could prove detrimental in the future (Cunitz, 2018). Water consumption and resource management can always be improved also in high-income countries.

Flush toilets contaminate drinking water to transport our waste and we spend energy and resources on cleaning it afterwards (Saner, 2019). This system makes very little sense in the 21st century and the ecological society we're trying to build (Saner, 2019). Especially when 4.2 billion people globally do not have safely managed sanitation services (World Health Organization, 2019).

Toilets have undergone many changes since their appearance five thousand years ago. But how will sanitation evolve from the current flush toilet system? What toilet system(s) can replace the commonly used flush toilet systems in developed countries such as Norway to support a more environmentally friendly sanitation system?

This research study aims to develop a holistic understanding of the current flush toilet system in Norway to identify where ecological sanitation systems can offer a more sustainable solution. The holistic systemic analysis approach was central to this research to get an overview of what other systems are related to sanitation and how interconnected systems assist or counteract each other. As a result this explorative qualitative research study will allow other researchers and developers to use the findings to understand what other systems need to be taken into account in order to implement a truly sustainable sanitation solution without losing sight of other systems that could be positively or negatively affected. The findings can also be used to educate members of society on the growing importance of environmental sustainability in the realm of sanitation.

Theory & Methods

Through academic articles, online research, and qualitative interviewing I collected information on three types of ecological sanitation systems: compost toilets, vacuum toilets, and incinerating toilets. Also the Klaro wastewater treatment designed for households with no access to sewer or septic was considered.
The user-friendliness, maintenance, noise, smell, autonomy, cost, capacity, integrability, waste output, waste treatment and safety of each system was analyzed to determine the range of application of each system and determine its potential to be implemented in small scale and low density areas (rural areas) and/or medium to high density areas (urban areas).

In addition, systems related to the topic of sanitation such as agriculture, economy, politics, legislation, culture, habits, behavior, consumption, pollution, water treatment, waste treatment, and the environment were explored and continuously visualized in a giga map using the stocks and flows method of Donella Meadows and the processor mapping technique.

The giga mapping and systemic thinking approach allowed me to grasp and work with super complexity. As toilets are just one element of a complex system, it was paramount to showcase all the systems that are interconnected to toilets to gain a better overview. By keeping as many systems connected to toilets in play for as long as possible throughout the process I increased the possibilities to generate holistic resolutions. The illustrated giga maps gave me the ability to convey and communicate complex problems to partners which allowed them to take an active role in the feedback process.

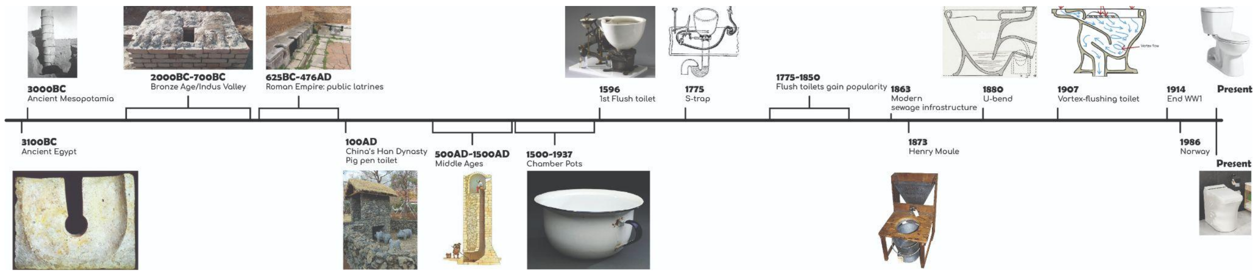
Throughout the project I collaborated with Petter D. Jenssen, a professor at the department of Environmental Science and Nature Management at NMBU who provided me with academic articles and field research. Petter D. Jenssen and interviewees provided feedback during the research project to correct content where necessary.

The ZIP analysis helped to identify intervention areas in the map where the selected ecological sanitation systems could provide a solution or areas that are crucial to take into consideration in order to successfully implement sustainable holistic solutions without causing negative ripple effects to other systems the solution might be interrelated with.

Based on the insights from the ZIP analysis several conceptual solutions were generated illustrating how ecological sanitation can be successfully integrated in urban and/or rural dwellings to improve the sustainable management of freshwater and human waste.

The hierarchy of intervention from Donella Meadows was applied to rank the solutions based on what level the solution would influence the system: mindset, purpose, interconnections, elements, behavior and/or event.

History of Toilets



“The flush toilet, more than any single invention, has 'civilized' us in a way that religion and law could never accomplish.” - Thomas Lynch, The Undertaking: Life Studies from the Dismal Trade

We can learn a lot from our history and past mistakes. For this reason I wanted to take a look at the history of dry toilets and flush toilets and understand what led to the successes and/or failures of different waste management systems.

The first toilets only appeared around five thousand years ago, which makes the toilet nearly as old as human civilization itself. As early humans began living together in larger and larger groups, an organized system for waste disposal quickly became a necessity. The original and most important purpose of a toilet was the promotion of hygiene, and that’s as true today as it was in 3000 BC (coway, n.d.).

Researchers can't say for certain what inspired these early sewage systems, but we do know that waste management is essential for public health. Untreated sewage is a breeding ground for dangerous microorganisms, including those that cause cholera (vibrio cholerae), dysentery (shigella) and typhoid (salmonella typhi). It would be several millennia before scientists fully understood the relationship between sewage and sickness, but the noxious odors of sewage have recorded associations with disease as early as 100 BCE (de los Reyes, 2021).

1. Ancient Mesopotamian 3000 BC (5000 years ago): Many ancient religious texts contain instructions for keeping waste away from drinking water and campsites. However, waste management took shape as early as 3000 BC. Ancient Mesopotamian settlements often had clay structures made for squatting or sitting in the most private room of the house. These were connected to pipes which used running water to move waste into street canals and cesspits. (de los Reyes, 2021)
2. Ancient Egypt 3100 BC: Egyptian toilets were designed specifically with water conservation in mind. They in general went hard on saving, believing in only using H_2O with the intent to reuse it. With no running water in Egyptian homes, even with dedicated rooms in which to bathe, Egyptians would pour water onto themselves at bath time, which was collected in jars and reused for agriculture and gardening. The Egyptians

would excrete onto seats into containers filled with sand, which would be cleaned out by the servants (Weird History, 2020).

3. Bronze Age 2000 BC – 700BC (4000 years ago): In some parts of the Indus Valley in northwestern India and Pakistan, nearly every house had a toilet connected to a city-wide sewage system (de los Reyes, 2021). These toilets served the simple but valuable purpose of carrying waste away from homes (coway, n.d.).
4. Roman Empire 625 BC – 476 AD (2600 years ago): Romans used public latrines. These public latrines could seat up to 20 Romans at a time, draining waste in water conduits below. By 100 AD, more complex sanitation solutions were emerging. The Roman Empire had continuously flowing aqueducts dedicated to carrying waste outside city walls. (de los Reyes, 2021). While a great way to flush away waste, it was a bad way to prevent rat attacks from open sewer lines and occasional fires from built up methane (Weird History, 2020). Roman toilets did keep waste out of the streets, but their hygiene left something to be desired. Historians believe that the Romans likely wiped themselves with a sponge or stick, which, like the toilet itself, was shared by everyone (coway, n.d.).
5. China's Han Dynasty 100 AD (1922 years ago): Chinese dynasties had private and public toilets, except their waste was immediately recycled. Most household toilets fed into pig pens (de los Reyes, 2021). The pigs would then eat the waste in addition to their other food. Once this was digested, the pig waste would be used as fertilizer thus eliminating the need for a sanitation system (Weird History, 2020). Pig toilets were an efficient waste disposal system for areas without plumbing infrastructure (coway, n.d.). Specialized excrement collectors gathered waste from public latrines to sell as fertilizer. In China, this tradition of waste management continued for centuries (de los Reyes, 2021).
6. Middle Ages 500AD – 1500AD (1522 years ago): Pit latrines, called gongs, became commonplace, and chamber pots were frequently dumped into the street. Castles ejected waste from tall windows into communal cesspits (de los Reyes, 2021). Great for castle hygiene, perhaps, but not so much for the town downstream (coway, n.d.). At night, so-called Gong farmers would load up the waste before traveling beyond city limits to dump their cargo. Europe's unsanitary approach persisted for centuries, but toilets themselves underwent some major changes. (de los Reyes, 2021)

   By the late Middle Ages, most wealthy families had commode stools, wooden boxes with seats and lids. And in the Royal Court of England the commodes were controlled by the groom of the stool. In addition to monitoring the King's intestinal health, the groom's intimate relationship with the monarch made him a surprisingly influential figure. (de los Reyes, 2021)
7. 1500-1937: Before the indoor flushing toilets were popularized in the 20th century, most people had to wander down to local cesspools in order to relieve themselves. This could also be a potentially hazardous trip to take at night, so rather than march down to a local cesspool, people would have chamber pots in their room. Chamber pots were small metal or ceramic containers designed to hold waste that was later emptied into pools or thrown out the window. They remained a popular way to go to the bathroom until World War Two and are even used today in some parts of the world where indoor plumbing is still not a thing (Weird History, 2020).

8. Sir John Harrington 1596: The next major leap in toilet technology came in 1596 when Sir John Harrington designed the first modern flush toilet for Queen Elizabeth. Its use of levers to release water and a valve to drain the bowl still inform modern designs. But Harrington's invention stank of sewage. (de los Reyes, 2021)
9. Alexander Cumming 1775: Scottish inventor Alexander added a bend or S-trap in the drainpipe to retain water and limit foul odors from sewers from traveling up the pipes into a home (de los Reyes, 2021).
10. 1775-1850: Thanks to the advances in the design of the flush toilet, demand increased with water closets, growing in popularity throughout the mid-18th and 19th centuries (Weird History, 2020).
11. Frankfurt 1863: In 1863 many cities had developed modern sewage infrastructure and wastewater treatment plants as cities experienced rapid growth (de los Reyes, 2021).
12. Henry Moule 1873: As populations continued to boom so did contagious diseases due to widespread unsanitary conditions. Cholera in particular, was the contagious disease of that time, whose spreading was aided greatly by poor sanitation systems. Because of this, the dry toilet was invented as a way to use the bathroom without water as the flushing mechanism. But rather, it would divert waste or use covering materials such as peat (partially decomposed organic matter) to absorb the liquid.

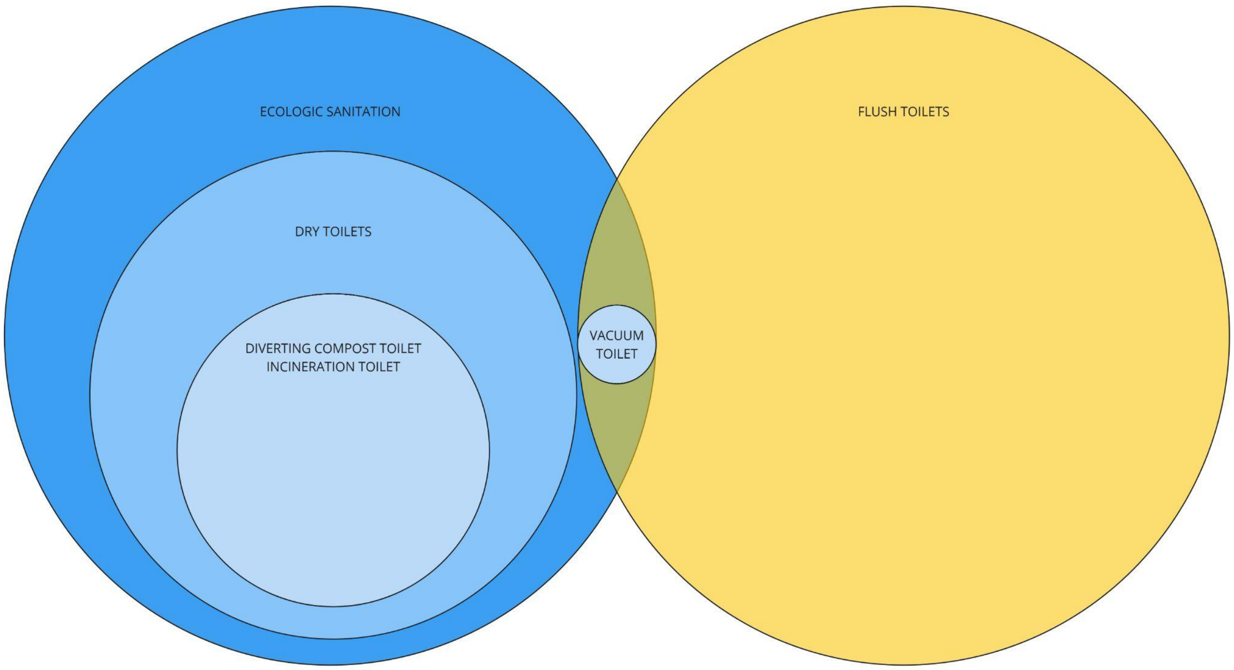
    First invented by an English priest named Henry Moule with a patent in 1873. He was able to get the design in schools and public hospitals in England and India. But despite cutting maintenance costs and eliminating odors associated with sewage systems, his design did not catch on. We can thank this failure today to all our flush toilets. (Weird History, 2020)
13. Thomas Crapper 1880: improved the S-bend plumbing trap by inventing the modern U-bend (de los Reyes, 2021). Crapper displayed his toilet products in showrooms and tried to sell his sanitation designs to the wealthy (Weird History, 2020).
14. Thomas MacAvity Stewart 1907: The vortex-flushing toilet bowl, still the global standard, was invented in 1907 by the Canadian Thomas MacAvity Stewart. The 20th century saw the rapid adoption of flush toilets in homes throughout the world including Norway. While global toilet styles differ, they all share the goal of being a hygienic, convenient waste elimination system (coway, n.d.).
15. 1914: After World War One, all new buildings built in the UK were required to include an indoor flush toilet.
16. Norway 1986: Dry toilets in Norway are used at places with no access to sewer systems but are not commonly used anymore in urban areas (Petter D. Jenssen).
17. Present: today toilets have a wide range of features, from the luxurious flush toilets to the sustainable composting and water saving toilets. (de los Reyes, 2021)

Even though toilets have undergone many iterations today annually 756,585 people still die globally from unsafe sanitation (Ritchie & Roser, 2021) and 4.2 billion people globally do not have safely managed sanitation services (World Health Organization, 2019). Putting these communities at risk of numerous diseases. To solve this problem, we'll need to invent new sanitation technologies and address the behavioral, financial, and political issues that produce inequity throughout the sanitation pipeline (de los Reyes, 2021).

Insights gained from the History of Toilets

- Dry toilets were mostly used in countries that had water scarcity, no running water, no sewer system or suffered from diseases, today this is still true.
- Water-based toilet systems, especially open sewer systems such as dumping feces in the street, cesspits, and cesspools, weren't successful at preventing diseases from spreading and polluting rivers due to the lack of wastewater treatment plants that treat waste or black water before releasing it into the environment.
- Dry toilets and water-based sewage systems weren't hygienic when the feces were left untreated. Such as the chamber pots that were emptied in the street or in cesspools, polluting rivers, and accelerating the spread of diseases.
- The flush toilet was invented in 1596 before the emergence of the modern dry toilet in 1873 and it grew in popularity throughout the mid-18th and 19th centuries. Despite cutting maintenance costs and eliminating odors associated with sewage systems, dry toilets didn't become widely used because flush toilets were increasing in popularity and were convenient to use. This proves the point that technical aspects and practices are interdependent and are the key components that contribute to user acceptance of a toilet system (Kaur Bhatti, 2021).
- Only the dry toilets from Henry Moule and China's Han Dynasty were successful at preventing pollution of the environment and spreading of diseases because the waste was immediately recycled by pigs or treated with covering materials.
- The noxious odors of sewage have recorded associations with disease as early as 100 BCE (de los Reyes, 2021), this goes to show that many cultures always had a disgust and aversion towards their own waste. Yet in eighteenth century Japan, Japanese citizens did not view human waste as unwanted waste, but rather as something of value. They were even arguing about who had the rights to collect it, keep it, and use it. The answer on why they had a different view than ours lies in the soil. Compared to many European and North American countries, blessed with an abundance of forests and fertile grounds, Japan had much less land that was suitable for agriculture. Large parts of Japan had soils that were sandy and low on nutrients. Without continuous fertilizing with human waste, they didn't yield rich harvests (Zeldovich, 2019). Agriculture and human waste are closely related and whether or not a nation has fertile soils dictates their culture towards human waste.
- Water-based disposal systems have been designed and implemented on the dogma of human excreta as a waste rather than a resource (Langergraber & Muellegger, 2005) through the concept of "flush and forget" (Esray, Andersson, Hillers, & Sawyer, 2001) (Kaur Bhatti, 2021). This is evident when we look at Western civilizations spending billions of euros on building expansive sewage systems that remove our waste quickly and efficiently and keep it as far away from us as possible (Zeldovich, 2019). It is this mindset that will be the main hurdle to get Western cultures such as Norway to welcome the integration of ecological sanitation such as dry toilets in their households. Even when they are aware that converting to ecological sanitation is better for the environment.

Ecological Sanitation



Sanitation can be broadly defined as a barrier between humans and their waste that can be established through facilities and services or a process (Evgenieva Kelova, 2022), provisioning clean drinking water that meets public health requirements and adequate sewage disposal with the main intent to protect human health. Sanitation systems differ in their implementation, operation as well as maintenance.

Toilets are the interface between the user and the sanitation system. Toilets can be combined with a variety of technologies for conveyance.

Ecological sanitation is a sustainable model that promotes the treatment of human excreta as a resource rather than waste, as well as using less freshwater for the sole purpose of disposing of human waste (Kaur Bhatti, 2021). This is possible when human excreta is viewed and used as a resource; to be recycled rather than disposed of negligently (Kaur Bhatti, 2021). Human excreta as a resource full of nutrients can be recycled back into the natural environment through proper management and sanitary treatment adopting treatment methods like dehydration or decomposition. By doing so ecological sanitation closes the gap between sanitation and agriculture resulting in a closed system known as an ecological loop (Kaur Bhatti, 2021). Without societal acceptance of the ecological sanitation model, sustainable development cannot occur (Kaur Bhatti, 2021).

Research that's done in the Oslo region shows that the water table in the Oslo region is falling rapidly. Oslo has experienced some summers where the municipality of Oslo had to advertise its citizens to spare water (Margel, 2023). Messages informing citizens to pee in the shower instead of flushing was one of the recommendations by Oslo municipality to save water (Margel,

2023). A less common tactic in striving for sustainable development is to extract nutrients from wastewater for utilization rather than releasing the nutrient-filled effluent into natural water bodies (Kaur Bhatti, 2021).
Essential plant nutrients for agriculture such as phosphorus, nitrogen, and potassium are found in rich quantities in human waste (Kaur Bhatti, 2021). Separating human excreta from water and composting it has a high fertilizing potential with benefits to plant growth which is similar to, or exceeds, artificial mineral fertilizers in agriculture (Kaur Bhatti, 2021).

Dry Toilets

Dry toilets are the interface of sanitation systems that do not use flush water to convey human excreta or block odors. The fundamental principle of dry toilets is the absence of water in the use, handling, and transport of human waste (Kaur Bhatti, 2021).
Human feces naturally break down into pathogen-free compost in the presence of oxygen and covering materials such as sawdust to absorb the liquid. Many different types of dry toilets exist, what differentiates them is how human waste is managed and treated. Dry toilets is an ecological sanitation system as it closes the loop between sanitation and agriculture.

Historically and still today dry toilets are commonly used in rural areas, areas without sanitary infrastructure, and in regions with water scarcity. Although dry toilets were invented in 1873 (Kildwick, 2019) the recent eco revolution has revived the potential use of dry toilets.
Dry toilets are a popular waste management solution in remote and sensitive areas because they offer safe, resilient, decentralized sanitation even during extreme weather events by storing, managing and treating waste on-site (Kaczala, 2006) saving millions of people from the threat of cholera, dysentery and numerous other diseases. The low demand infrastructure and investment makes dry toilets available for a broad range of socio-economic scenarios (Kaczala, 2006).
Because dry toilets are used in low-income countries and rural areas they are commonly associated with a simple, rudimentary type of latrine but goals like ensuring availability and sustainable management of water and sanitation for all (SDG 6, UN) and to eliminate waste, circulate materials and regenerate nature require rethinking of this perception (Evgenieva Kelova, 2022).
When correctly planned and implemented, dry toilets can provide an environmental, ecological and economical friendly solution to current sanitation problems in both developed and undeveloped countries.

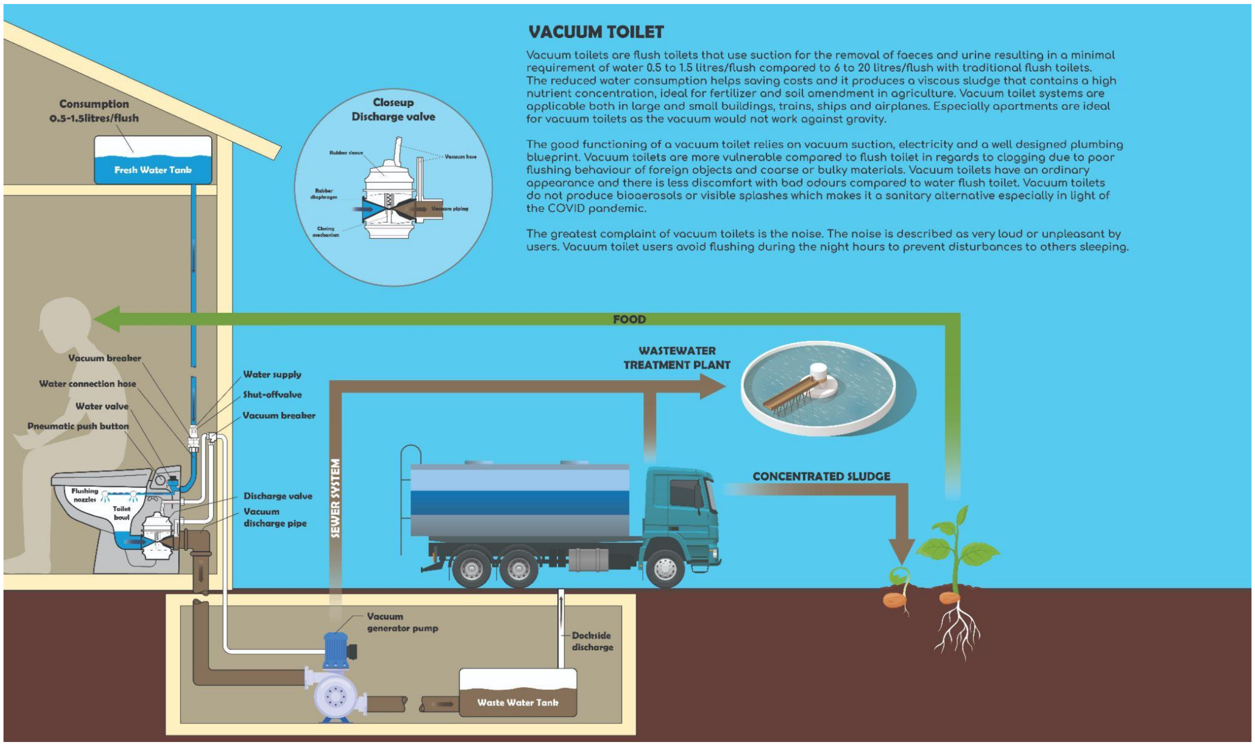
However, the planning process and implementation of such systems are not simple. It must follow specific requirements in order to achieve a desirable technical function and efficiency and consequently to be considered as truthfully viable economically, environmentally and hygienically (Kaczala, 2006).

Dry toilets with household-level technology and on-site treatment are often treating waste in little controlled treatment conditions, limited by the prevailing and varying environmental conditions. The treatment process and the end product differ due to the variability in the composition of excreta, additional input materials, how the treatment is managed, and the local context (Evgenieva Kelova, 2022). The end product can be a valuable resource when its treatment is monitored and the application regulated.

Among the existing sanitation systems, dry systems are more interesting from a resource-oriented management standpoint (Evgenieva Kelova, 2022). They eliminate the use of water and the volume of waste along with concentrating the nutrients. Water is a precious resource that is under increasing pressure and it holds more value clean than recycled (Evgenieva Kelova, 2022). There is a clear argument that dilution of excreta with water is counteractive to its management and recycling (Evgenieva Kelova, 2022). Using drinking water to convey the excreta is a convenience that is not achievable and sustainable everywhere (Evgenieva Kelova, 2022).
As the capacity of modern wastewater treatment facilities are overloaded which prevents villages from developing, dry toilets facilitate village development by reducing the load on existing wastewater infrastructure.

This study took a closer look at three ecological sanitation toilets: vacuum toilet, incinerating toilet and diverting compost toilet. The incinerating and diverting compost toilets fall under the dry toilet category as they use no water to transport the waste to a wastewater treatment facility. The vacuum toilet however isn’t a dry toilet as it uses water and air suction to dispose of waste yet it still qualifies as an ecological sanitation system as it produces a viscous sludge that is excellent for fertilizer use.

Vacuum Toilet System



What is a Vacuum Toilet?

Vacuum toilet systems are a type of flush toilets that rely on vacuum suction for the removal of feces and urine resulting in a minimal requirement of water 0.5 to 1.5 liters/flush compared to 6 to 20 liters/flush with traditional flush toilets (Kaur Bhatti, 2021).

Advantages & Limitations

The reduced water consumption helps saving costs, allows for onsite waste treatment and it produces a viscous sludge that contains a high nutrient concentration, ideal for fertilizer and/or soil amendment in agriculture (Kaur Bhatti, 2021). Vacuum toilet systems are applicable both in large and small buildings, trains, ships and airplanes. Water can be transported vertically against gravity, smaller commonly available pipe diameters can be used and pipes can be routed around obstacles.

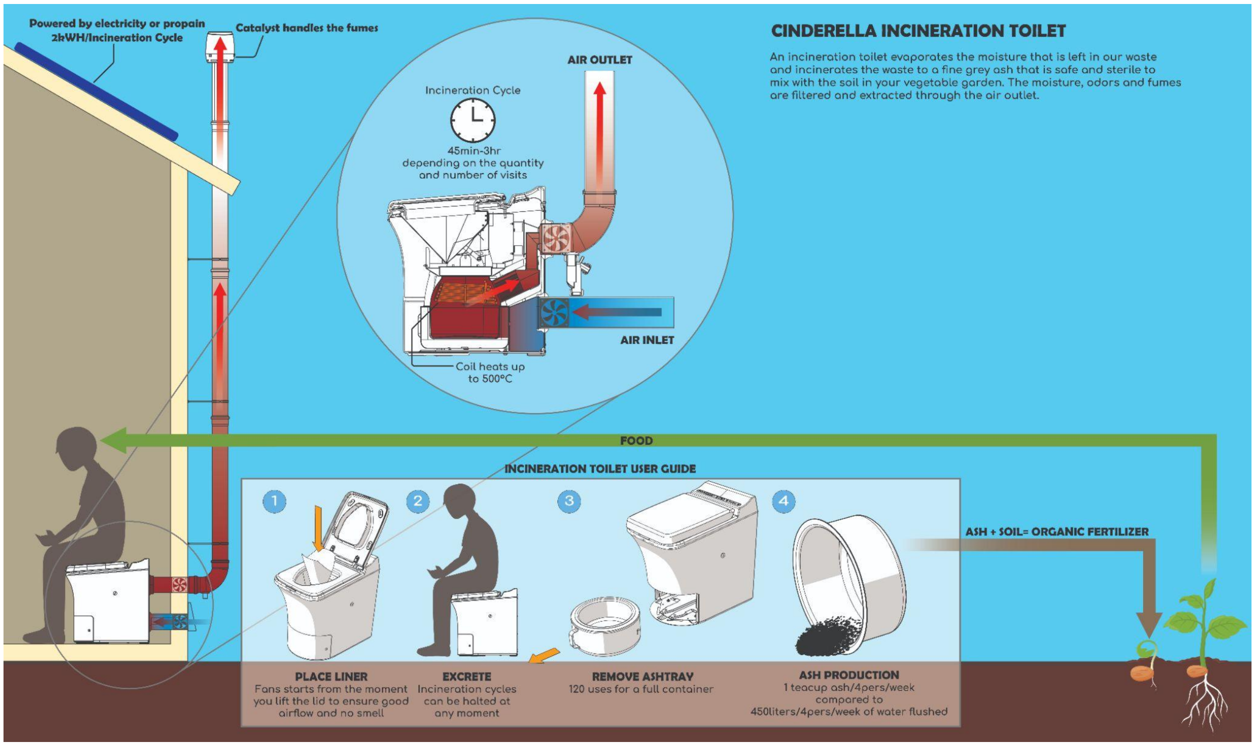
The good functioning of a vacuum toilet relies on vacuum suction, electricity and a well designed plumbing blueprint. If there's an electricity outage the toilet can't be used. (Kaur Bhatti, 2021).Vacuum toilets are more vulnerable compared to flush toilets in regards to clogging due to poor flushing behavior, flushing foreign objects and coarse or bulky materials (Kaur Bhatti, 2021). Municipal services remove wastewater from the holding tank and transport it to farmers or a wastewater treatment facility. Vacuum toilets have an ordinary appearance and there is less discomfort with bad odors compared to water flush toilets. Vacuum toilets do not produce bioaerosols or visible splashes which makes it a sanitary alternative especially in light of the

COVID pandemic (Kaur Bhatti, 2021). Vacuum toilets are used in places where sanitation remains a high priority issue dealing with communicable diseases and sustainable development (Kaur Bhatti, 2021). The system is difficult to regulate in communities and public buildings where users hold no responsibility for compliance and there is little liability for poor flushing behavior restricting the system to operate at its full potential (Kaur Bhatti, 2021).

The key aspects for not accepting vacuum toilet systems for future development by users are the noise from the vacuum toilets, and smell when the holding tanks are emptied (Kaur Bhatti, 2021). The noise is described as very loud or unpleasant by users. Vacuum toilet users avoid flushing during the night hours to prevent disturbances to others sleeping (Kaur Bhatti, 2021).

Toilets uphill and furthest from the vacuum pump have less suction power. Sharp bends create areas prone to clogging. Badly designed plumbing blueprints can result in a problem caused by one household to affect other residences. For example a loss of vacuum/flooding/bad odor or any other problem usually caused by a clogging or blockage (Kaur Bhatti, 2021).
Vacuum toilet systems are complex and consist of a lot of moving parts increasing the likelihood of it being more high maintenance.
Unless vacuum toilets are connected to a rainwater source they rely on a municipal water supply demanding compliance with strict regulations and costs.
It's not easy to install vacuum toilets in an existing home because you have to make special allowances in the building process such as connecting it to a water supply and digging in a septic. Vacuum systems are not ideal for replacing flush toilets because they need a smaller pipe diameter. Thus the whole plumbing layout needs to be replaced which is too expensive (Kaur Bhatti, 2021).

Cinderella Incinerating Toilet System



About Cinderella

Cinderella was launched almost 26 years ago on the market, so they have a long experience in the incineration technology (Margel, 2023). Initially it was launched for cottage owners in remote places with no access to water or septic tanks (Margel, 2023). Cinderella provided more comfort for dwellings that previously only had access to outhouses (Margel, 2023). As the popularity for the system grew, the development has also gone towards mobile homes and businesses. For instance mining and fish feeding platforms, all places where access to septic and/or water is either very expensive or not possible. When building bridges for instance, the workers are on top of big platforms, many meters above the ground. It's dangerous and costly to bring workers up and down, because it takes a lot of time, so installing a toilet up at the top of the platform while building a bridge saves money (Margel, 2023).

What is an Incinerating Toilet?

An incinerating toilet evaporates the moisture that is left in our waste and incinerates the waste to a fine gray ash that is safe and sterile to mix with the soil in your vegetable garden. The moisture, odors and fumes are filtered and extracted through the air outlet.

Application

Incinerating toilets are ideal for people that want a simple and safe system that doesn't require any handling of the waste after it has been used. The only thing left to do is to either dispose of the ashes in a compost bin or reuse the ashes for soil amendment in the garden. The low volume of what is left after the incineration process makes this sanitation system ideal for people that want to have a waterless toilet but don't have the space or time to learn and manage a composting toilet. The only drawback is that this system requires either electricity or propane to run it. The fumes are safely filtered, and the installation can be done in existing houses or new houses, which makes this system very adaptable to many different situations and demands. The nutritional value of the ashes is debatable but mixing the ashes with organic soil helps to fertilize the soil.

The introduction of Cinderella incinerating toilets has helped solve different environmental challenges in multiple countries. Including Canada, where composting toilets along the great lakes are common on the islands and are a source of bad smell; South Africa in 2018 when it was facing a water crisis; replacing compromised sanitation infrastructure due to forest fires in Australia and replace flush toilets connected to cesspools contaminating the ocean and killing off the coral reef in Hawaii 2020 (Margel, 2023).

Cinderella hasn't developed an incineration solution that can handle several story buildings. Cinderella has however set up and tested out for some schools in Greenland a magnified incineration process connecting the toilets underneath the floor. So there are ways to develop the incineration technology to handle the waste of multiple households (Margel, 2023).

Function of the Cinderella Incinerating Toilet

A Cinderella incinerating toilet needs an inlet and outlet of air, just like a wood burning stove (Margel, 2023) to feed the incineration process with fresh air and filter the fumes through a catalytic filter before extracting the fumes out through the chimney. Cinderella tests if the fumes contain noxious gasses of any kind in independent laboratories to make sure that the products are certified according to regulatory demands in the countries and markets that the Cinderella toilets are used in (Margel, 2023). Apart from the exhaust air also the ash is tested to make sure that it's completely sterile containing no pathogens or residues of any kind (Margel, 2023).
The toilet runs on electricity or on propane gas. Electricity can be provided through the grid or from solar panels.

Cinderella Incinerating Toilet Process

From the moment you lift the lid fans start to ensure good airflow and no smell. Before using the toilet you place a bowl liner which is comparable to an overgrown coffee filter into the bowl (Margel, 2023). After excreting into the bowl liner you close the lid and hit the start button. Inside the, the bowl opens and the bowl liner with the contents falls to the bottom where the incineration happens (Margel, 2023). The bowl closes and a coil that heats up to 500°C safely burns the content and all pathogens to a minimal amount of ash (Margel, 2023). At the bottom, there is a hatch to remove the ashtray. The ash is completely sterile and can be thrown in the household waste or used in the garden for soil amendment. It takes about 120 uses to fill the ashtray and an incineration cycle takes about 45 min to 3 hours depending on the quantity and number of visits. If a new person wants to use the toilet, the incineration cycle can be halted safely at any moment. After the lid is closed the incineration process resumes.

Advantages & Limitations

A family of four produces 1 teacup ash/week (Margel, 2023). This is almost negligible compared to 450 liters of water flushed away over the course of a week for a family of four with a flush toilet (Margel, 2023).
As the bowl liner collects the feces the bowl stays clean and reduces the need to clean the bowl regularly. The toilet does demand a change of habit because for every visit you need to place a bowl liner. However children that have grown up using an incinerating toilet understand the correct behavior pattern right away because it is an easy habit to get used to (Margel, 2023).
The toilet is a little bit higher compared to flush toilets to accommodate the heating elements at the bottom that burn the waste. However a stool is provided for children to reach the toilet. The simpler and more user friendly a toilet system is, the more adaptable it is to broad use (Margel, 2023).

The toilet doesn’t make any obtrusive sounds, it makes less noise compared to a dishwasher. The system is closed when incinerating waste, the toilet is insulated and a child can touch the outside of the toilet during an incineration cycle and not be burned (Margel, 2023).

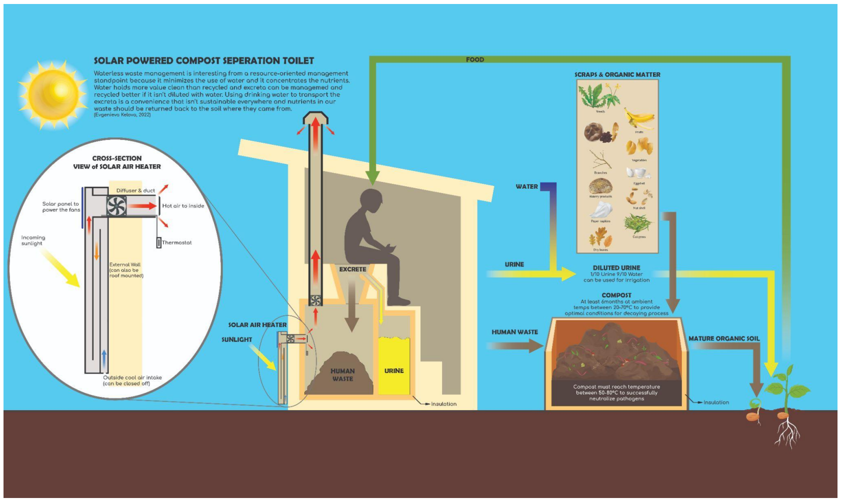
The backdrop of the incinerating toilet is that it requires 2kWh of electricity per incineration cycle or it needs to be fueled with propane gas. The Cinderella toilet is not cheap and would be a significant purchase for anyone, prices start at 4,351€.

The nutritional value of the ashes by themselves is questionable and needs more testing. However, the mixture of ash and soil promotes plant growth similar to the recurrence of plant growth after a forest fire. That’s why many people use it as fertilizer in their gardens.

Installation of the Cinderella Incinerating Toilet

Even though Cinderella provides intuitive installation videos, it is recommended to install the Cinderella toilet system by a professional to ensure the correct inlet and outlet of air, the chimney is at the correct height and the connections are airtight (Margel, 2023). Compared to a vacuum toilet the installation of an incinerating toilet is easier because it doesn’t need access to water or a septic tank and ashes from an incinerating toilet don’t need to be treated and handled unlike waste from a compost toilet (Margel, 2023). The Cinderella incinerating toilet doesn’t need any special allowances in the building process which makes it compatible with new homes and existing homes.

Diverting Compost Toilet System



What is a Diverting Compost Toilet?

The idea is simple: a diverting compost toilet collects urine and feces separately at the source without using precious potable water. Human waste is treated just as any other organic matter in a not dissimilar way to how kitchen waste is composted. Instead of causing nutrient pollution in local water bodies, our nutrients can be composted to safely and effectively grow plants and support local food production.

Application

This toilet system is for people that strive to be more conscious about their impact on the environment. These eco-minded people want to avoid being connected to the sewer system or communal water supply to cut costs and be as self-reliant as possible. They want a robust, reliable, and ecological toilet system that doesn’t require external power or fuel sources to run it. By using this toilet, they are convinced that they contribute to saving the environment by consuming less water and reintroducing nutrients back to where they came from. They have space and time to compost, and they are committed to learn and apply the required knowledge to monitor and regulate the quality of the compost process.

Advantages & Limitations

Feces and urine are separated at the source using special collectors to allow separate management. It facilitates storage, management, treatment and recycling of the separated excreta and closes the loop by returning nutrients and organic matter back to the environment for better soil quality and food production (Evgenieva Kelova, 2022).Diverting urine is recommended because an appropriate moisture level, ambient temperature and airflow must be carefully maintained in the defecation chamber to ensure optimal conditions for composting. High urine content would bring constraints to the maintenance of these desirable conditions by adding too much moisture.

Urine is particularly rich in phosphorus, a vital component of manufactured fertilizer that is currently mined from phosphate rock, a finite resource, so diverting urine is a good idea (Saner, 2019). Urine generally poses little threat to human health and contains the most part of useful nutrients (88% of the nitrogen, 67% of the phosphorus, and 71% of the potassium) (Kaczala, 2006). Urine can be brought to a central treatment location, where it is pasteurized and distributed to farmers, it can be filtered with activated carbon but you lose some of the nutrients in the process or it can be used in the garden (Saner, 2019) after diluting it with water (1 part urine to 10 parts of water). As phosphorus is a nutrient that increases plant growth; it's great for food crops, but it's not great for aquatic ecosystems because it feeds algae blooms that suffocate marine life and produces algal toxins which can be harmful to human and animal health (Statistics Norway, 2022). Therefore, it is important to dilute the urine before using it to irrigate the garden or field crops.

Composting is the best process to preserve the nutrients in the waste and break it down to plant usable form (Evgenieva Kelova, 2022). However, a diverting compost toilet is not a total waste handling solution. After handling is needed to break down the feces to plant usable form and get rid of medication residue and pathogens. Depending on where the compost pile is located some transport of the waste to the compost pile is needed. In face of this fact, the treatment process towards desirable quality is recommended to be done in two steps (Kaczala, 2006).

- **Primary Processing**
  The principal purpose of primary processing is to reduce the volume and weight of fecal material to facilitate storage, transport and further necessary treatment. Primary processing takes place in the container underneath the toilet where the feces are kept. During this containment, the number of pathogens should be reduced as a result of storage time (usually is required about 6–12 months); natural decay; dehydration; increased pH, and the presence of other predator organisms (Kaczala, 2006).
- **Secondary Processing**
  The principal purpose of the secondary treatment is to provide a final treatment to meet public health requirements. This final step could be done principally through thermal decomposition (increase of temperature) and even an additional period of storage (Kaczala, 2006).

If managed properly, feces which contain most of the pathogens can be safely used as a fertilizer after storage either at ambient temperatures (20°C) for two years or composting at high-temperatures (50-70°C) for six months (Kaczala, 2006). The pathogen die-off takes place in consequence of UV radiation, dryness and competition with other soil organisms (Kaczala, 2006). The addition of carbon-based organic matter after each defecation into the compost chamber such as soil, food scraps, straw, wood shaving, wood ash, toilet paper, garden cuttings or saw dust activates the composting process and assist the dehydration, reduction of odors and control of moisture content (Kaczala, 2006).
It is recommended to remove the humified content once a year. An inspection door allows the operator to easily remove the composted content and monitor if the compost process is working efficiently.

In dry sanitation systems composting is the most common method to recirculate the nutrients in excreta (Strande and Brdjanovic, 2014). Backyard composting is a widely known and accepted practice also for other organic household wastes. The high temperatures (50-70°C) reached during composting have been proven to eliminate pathogens and sanitize the material but successful composting is not easy to achieve in self-contained toilets or small-scale domestic composters.

A constant ambient temperature of at least 20°C allowing the compost to reach temperatures of at least 50-70°C is needed to ensure a successful composting process to break down all pathogens and medication.
Insulating the composting chamber to create a thermal barrier prevents heat loss to the environment produced by the composting process is important to control the outcome and reduce the variability of the end product (Evgenieva Kelova, 2022). Additional solar heating minimizes high moisture content (Kaczala, 2006) especially in cold climates.
If additional heat is not applied, cold climates and extended periods of freezing temperatures reduce the compost processes speed and efficiency. The result is suboptimal functioning of the toilet, slower composting rate, increased moisture and odors (PetterD. Jenssen et al., 2023).

Warm air can be produced with a solar collector (PetterD. Jenssen et al., 2023), generating sufficient heat to create a thermal convection to pull the air through the system (Kaczala, 2006). The air flow is enhanced by a solar powered fan (PetterD. Jenssen et al., 2023), providing additional oxygen, evaporating of the excess moisture through the vent pipe, and odor control (Kaczala, 2006). Thermostatically controlled heating allows to accumulate heat and keep desirable temperature ranges to establish dry and odor-free humus (Kaczala, 2006).

Major costs and strict regulations associated with connecting to sewage can be avoided by using a diverting compost toilet while still enjoying the same comfort and convenience as with a flush toilet.

Some limiting factors of diverting compost toilets that withholds people from being able to enjoy the advantages of this dry toilet are:

- The lack of time and physical space (garden) to let waste compost for 1-2years.
- Required effort and knowledge to handle and manage the compost to get the desired end-product.

Future of Dry Toilets

Dry toilets will continue saving the 2 billion people that don’t have access to toilets or latrines from spreading diseases in areas that don’t have access to sewer systems (World Health Organization, 2022). Clean, safe water treatment cannot be taken for granted (Saner, 2019).

Today, dry toilets are predominantly used recreationally for example in cottages or recreational vehicles rather than in residential homes (Margel, 2023). But as awareness about environmental

issues we are facing increases the trend of using dry toilets is also moving towards residential homes.
People are increasingly open to the idea of composting toilets (Saner, 2019), for example they are frequently used at festivals to collect the waste and distribute it to local farms.
Even though in some countries these dry toilets were largely abandoned as conventional systems became more convenient, there is a clear realization nowadays that conventional systems are unsustainable and a revival of these non conventional approaches such as dry toilets can be seen (Kaczala, 2006).

It can be suspected that “flush and forget” will continue to be the dominating desire in the future. Therefore a logical trend would not be the complete rejection of flush toilets but rather adapting the existing flush toilets to consume very low amounts of water per flush (Lewis-Hammond, 2014).

A day will come when even urban dwellings could be composting human waste. Humanure could be collected by residents in a block of flats before being carted off and composted, or it could be processed through a methane digester and that energy could be used within the building itself (Saner, 2019).

More research needs to be done where different toilet solutions are tested under reliable simultaneous evaluation and comparison in such a manner that could bring information regarding their characteristics, costs, product life cycle as well as the possibility to identify under which circumstances these different systems may perform efficiently (Kaczala, 2006).

As more choice of dry toilet systems becomes available ranging from simple and extremely affordable to high-tech and expensive, dry toilets will be suitable for underdeveloped and developed countries, low density rural areas and even for medium to high density urban areas (Kaczala, 2006).

Waste Treatment Systems

There are mainly two types of waste treatment systems, centralized and decentralized waste treatment systems.

Centralized Waste Treatment System

Centralized waste treatment systems collect, treat and dispose wastewater in larger volumes from a greater surrounding. The conventional domestic wastewater management is centralized with a sewer system for collection and transport, a treatment plant for removal of pollutants and effluent discharge to a water body. Such systems, however, serve only 34 % of the world population (WHO/UNICEF, 2021).

Advantages & Limitations

The municipality is responsible for maintenance and repairs, residents don't need to worry about organizing or paying for repairs. That makes the system convenient and problems are fixed by professionals.
Centralized waste treatment systems work as long as you have a public waste treatment facility nearby. Preventative measures need to be in place to prevent problems and mistakes that could have easily been avoided (Kaur Bhatti, 2021).

Decentralized Waste Treatment System

Decentralized waste treatment systems manage (collect, store or empty), treat & redistribute clean water and wastewater from the point of use. Waste is treated at the source, or a service provides sealable, removable containers for collection of human excreta on a regular basis and transport them to treatment facilities (Evgenieva Kelova, 2022).

Advantages & Limitations

Decentralized systems have environmental benefits by preventing pollution at the source, recycling nutrients, reducing energy requirements (Oarga-Mulec et al., 2023) and consuming less water to transport waste. Building and operating these systems is often much less expensive than off-site alternatives (Kaczala, 2006).

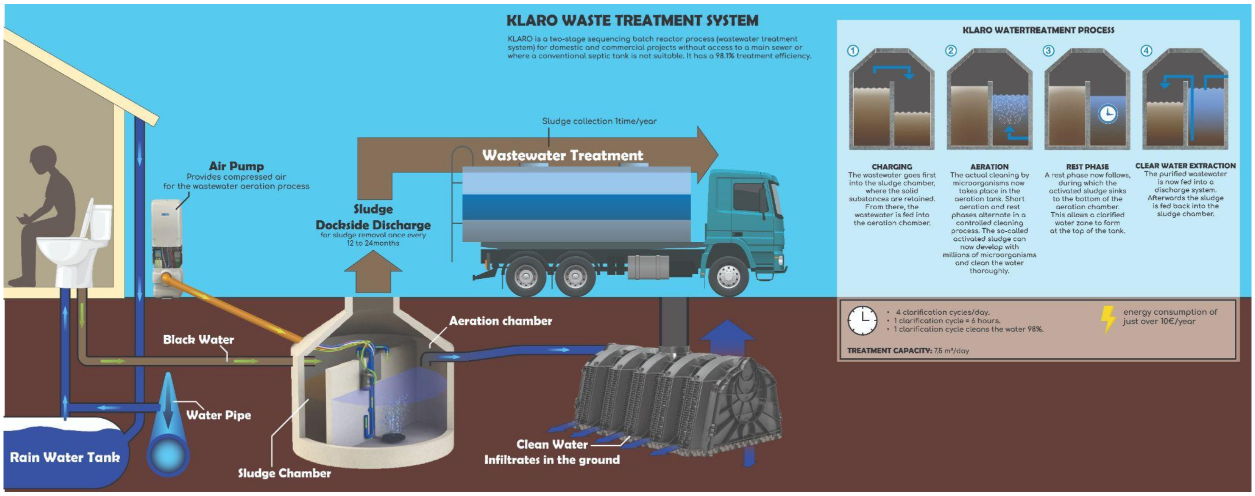
For rural areas and in low- and middle income countries without high coverage of sewer connections, decentralized and onsite sanitation are more common and practical (Evgenieva Kelova, 2022). On-site sanitation facilities are can also be found in developed countries where the infrastructure is missing, unfunctional, or does not make economic sense, as often is the case in rural locations (Evgenieva Kelova, 2022).

In contrast to the conventional sewer systems, where all wastewater streams (domestic and communal) are mixed, on-site facilities can be more easily designed or redesigned to separate the flows. Source separation enables better treatment and more possibilities for recycling of the waste (Larsen et al., 2009).

Decentralized waste treatment systems should only be constructed if there are clear intentions and enforcements in place to ensure local treatment of the greywater and exportation for black water. Without a proper plan in place, decentralization is futile.

The safety and quality is harder to monitor when waste is treated at the source (Solberg, 2023). Therefore it is important to have regulations and the possibilities to test sample pollutants in the composted waste to ensure safe treatment and reuse on crop fields.

Klaro Wastewater Treatment System



Klaro system in its essence is a scaled down wastewater treatment plant for homes that have no access to a main sewer or where a conventional septic tank is not suitable.
The Klaro system runs 4 clarification cycles/day. 1 clarification cycle takes 6 hours and cleans the water 98%. The treatment capacity of one Klaro tank is 7,5 m³/day. The Klaro wastewater treatment system consumes just over 10€/year on electricity. Sludge is removed by an annual municipal sludge collection service and brought to a municipal wastewater treatment plant for further treatment.
The lack of the Klaro system to close the loop between sanitation and agriculture makes it unqualified to be considered as an ecological wastewater treatment system.

A decentralized wastewater treatment system such as the Klaro system is however effective at reducing the load on existing municipal wastewater facilities that are already running at maximum capacity allowing communities to develop and deal with climate change, extreme weather events and rising water tables with more ease.

Klaro Wastewater Treatment Process

The Klaro system treats wastewater in four phases:

Phase1: Charging

The raw sewage enters the sludge chamber, where the solid substances are retained. From there, the black water is fed into the aeration chamber.

Phase2: Aeration

The actual cleaning by microorganisms now takes place in the aeration tank. Short aeration and rest phases alternate in a controlled cleaning process enriching the water with oxygen. The oxygen in the water produces millions of microorganisms also known as activated sludge which feed on the waste products and clean the water thoroughly.

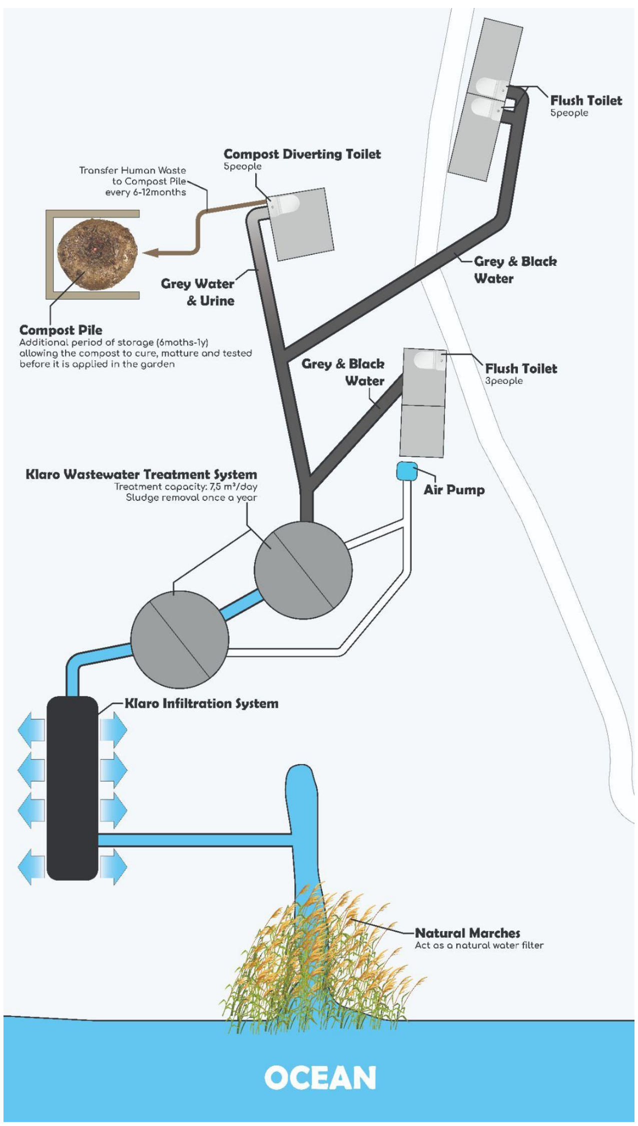
Phase3: Rest Phase

During the rest phase the activated sludge settles on the bottom of the aeration chamber and a layer of clear water forms at the top of the tank.

Phase4: Clear Water Extraction

The clear water is extracted from the tank and returned to nature. Afterwards the remaining sludge at the bottom of the aeration chamber is fed back into the sludge chamber.

Field Trip



I visited a household located at the coastal line of Tjøme that uses two Klaro wastewater treatment tanks (to increase the capacity to treat wastewater) and an infiltration tank to safely dispose of black water into the ocean. The black water comes from one urine diverting compost toilet, several flush toilets and the gray water produced by four households.

The municipality collects the remaining sludge at the bottom of the Klaro wastewater treatment tanks once a year and transports it to the municipal wastewater treatment plant for further treatment. According to the homeowner the collection interval could be extended even further.

The urine diverting compost toilet diverts the urine to the Klaro system and collects feces in a chamber underneath the bathroom. An inspection door outside the house allows the homeowner to easily remove the composted content and monitor the compost pile. After removal, the compost gets an additional period of storage, allowing the compost to cure and mature before it is applied in the garden. The Klaro infiltration system lets the treated water slowly soak into the ground. The benefit of this particular setup is the presence of natural marshes that acts as a natural water filter before the cleaned water is released into the ocean.

Safety

Human excreta also contain hazards like pathogens and environmental contaminants such as heavy metals and organic pollutants (Krause et al., 2021). Urine carries pharmaceutical residues and feces can contain infectious virus particles without the human host necessarily exhibiting clinical signs (Krause et al., 2021). Therefore, an important part of the management of excreta is minimizing the risk of pathogen transmission to the environment. Heavy metals and microplastics are generally found in lower concentrations in human excreta compared to wastewater or other organic wastes and fertilizers. For this reason, their concentrations are not a cause of concern in products from dry toilets and their application as fertilizer (Krause et al., 2021). The organic pollutants that can be found in human excreta are predominantly pharmaceutical residues. Research has been shown that for most pharmaceutical residues, the degradation in soils is better than in water, and only relatively small amounts have been found taken up by plants, which would not pose risk to human health (Evgenieva Kelova, 2022).

How to integrate a sanitary system?

To integrate a sanitation system that is accepted by the user you must understand the user first (Kaur Bhatti, 2021). It is crucial to understand the beliefs, thoughts, and perspectives of users to determine if the population is comfortable and accepting of the sanitation system (Kaur Bhatti, 2021) you are trying to implement.

Often a new problem is developed in the process of striving for environmentally friendly solutions (Kaur Bhatti, 2021). Hence why the planning of a sanitary system needs a holistic approach to integrate the sanitation system successfully. Aspects such as: climate, terrain, plumbing layout, homeownership (private or semi-private recidency; renting or buying), construction, cost, operation, communication, education, prevention, cleaning, maintenance, responsibility, inspection, waste treatment, user habits and user needs should all be taken into account (Kaur Bhatti, 2021)
The whole ecosystem from what we eat (cattle, agriculture) to how we process waste to preserving the soil quality should be considered.
A calculated plan ensures the system will be fully operational and eliminates the need for surplus expenses later on (Kaur Bhatti, 2021).

One Health

To get user compliance when implementing ecological sanitation, users need to be aware of the “One Health” approach. “One Health” indicates that all components are interconnected and recognize that the health of one component affects the others.

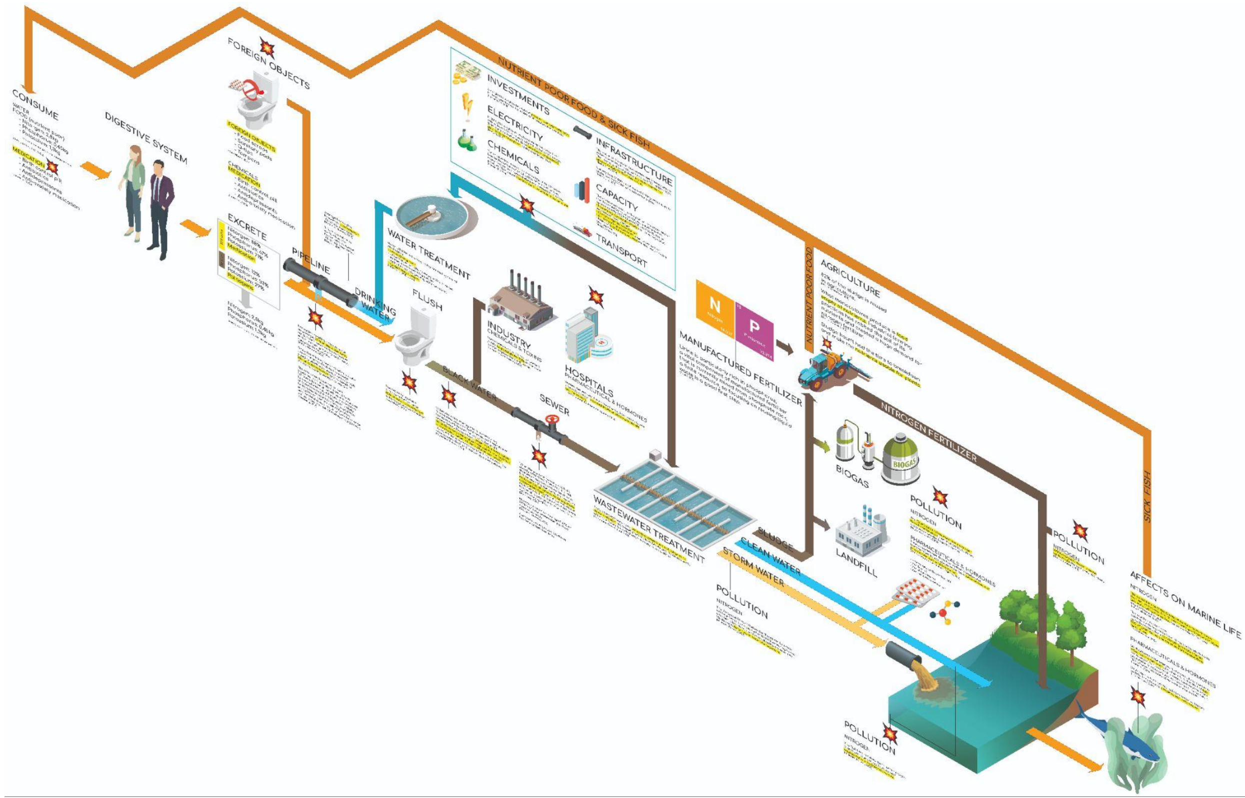
The health of humans depends on the quality of the food that is being consumed. The quality of the food depends on the plant available nutrients present in the soil. And nutrient rich soil depends on nutrient rich human waste.

The “One Health” system clearly illustrates how the intake of medication would negatively impact other components in the system but also how ecological sanitation systems could reinforce the “One Health” positive feedback loop.

Only a small part of the nutrient content of the food is retained by humans, and the nitrogen and phosphorus excretion is at or near 100 % of the intake. Returning these nutrients back to the soil and food production is important for nutrient cycling and soil quality. Currently, only a small part is recycled to land application, while the majority is disposed of as a waste driven to landfills or as an effluent discharged to water bodies. As a result, the nutrients and the organic matter create a burden to the receiving environments, while they are lost to soils and food production. The recycling of human excreta with ecological sanitation, provides waste and pollution reduction but also closes the loop between agriculture and sanitation and could address future challenges for fertilizer availability and better nutrient management (Evgenieva Kelova, 2022).

To truly strive for sustainable living, nutrient recycling in addition to the reduction of freshwater use and consumption is fundamental (Kaur Bhatti, 2021).

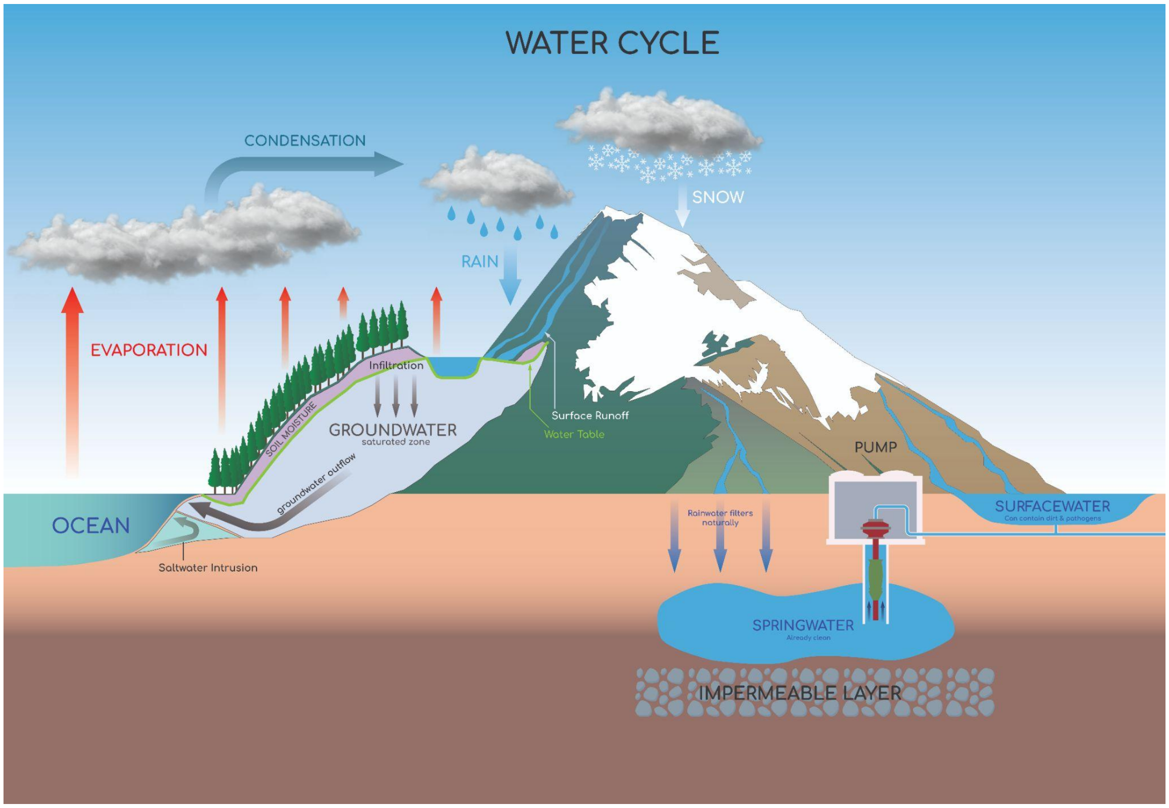
Areas of Opportunity



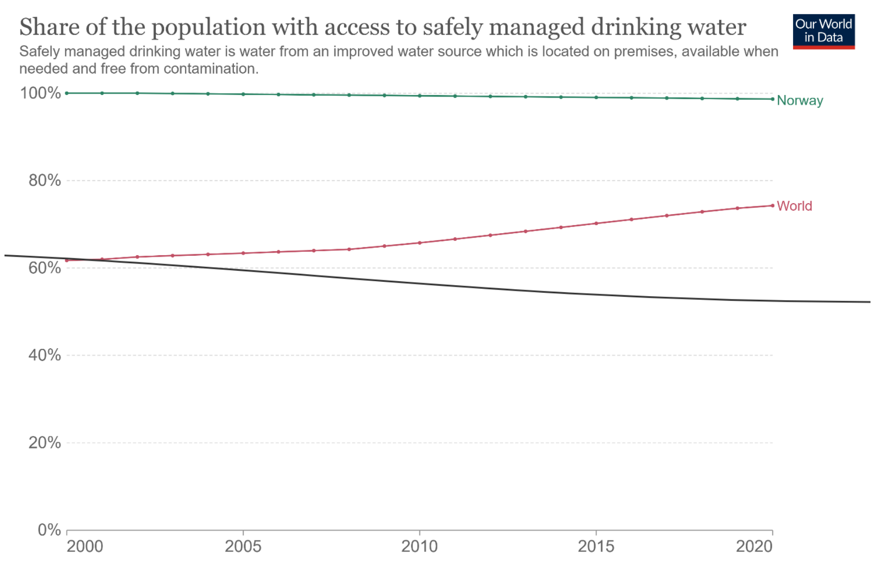
Through giga mapping and diverging the currently used flush toilet system, sewer system and wastewater treatment system in Norway, I identified several areas of opportunity where ecological sanitation could potentially offer a more sustainable solution. These areas are structured using the processor map below. In the following chapters I will discuss these areas of opportunity in more detail.

Fresh Water Supply

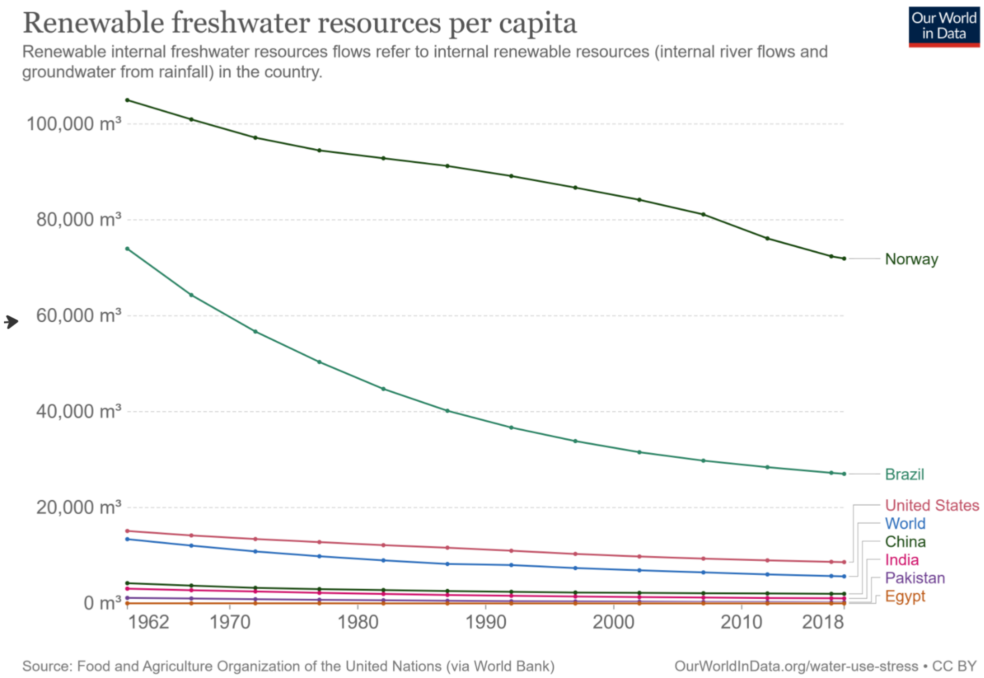
Water is a renewable natural resource. It doesn't regrow like trees but it moves in cycles. It goes from one place to another, and often back where it started from, again and again (Meadows , 2019). As water is a **renewable resource** it must be used at or below the rate at which it can replenish itself. Meanwhile, it takes weeks, even months for rain that falls on the land to infiltrate deep into the ground (Huyghebaert, 2023). If the water table remains low this will allow more saline water from the ocean to seep into the ground and salinizes the groundwater.



Rates of water withdrawals in Norway are below the rates of freshwater replenishment (Ritchie & Roser, 2018). As a result 99% of the Norwegian population enjoys universal access to safe and affordable drinking water, and adequate and safe sanitation for all (United Nations, 2023). However, this is not to say Norwegians are not facing great challenges when it comes to sustaining or improving their water supply in the future (Reichborn, 2013).



90 % of the water supply in Norway is based on surface water such as lakes and rivers, while 10 % is based on groundwater. The reason for the limited use of groundwater is ready access to abundant fresh surface water in Norway (Dagestad & Venvik, 2021).
To maintain sustainable water resources, rates of water withdrawals must be below rates of freshwater replenishment and water sources should remain pollution free. If rates of freshwater withdrawal begin to exceed the renewable flows of rivers and groundwater from rainfall, resources begin to decline. As we see, per capita renewable freshwater resources are declining in many countries as a result of population increases (Ritchie & Roser, 2018).



Few people experience that tap water for drinking is scarce in Norway. 2018 was an exception, when Oslo had to introduce water savings, people were not allowed to water their gardens and were asked to limit their use of clean tap water. For now that was an exception to the norm, but prognoses show that climate change might make this happen more often. Infact Oslo had another dry summer in 2022 (Margel, 2023), due to unusual little snowfall and precipitation.
In Oslo, the situation is already precarious as 90% of the tap water in the city depends on a single source, Maridalsvannet. This makes Oslo vulnerable, for instance two consecutive dry years could put a strain on water provisions in Oslo (Borgan, 2019). Oslo is therefore working to establish a new source for tap water by 2028. Population growth in Oslo also puts a strain on the water supplies. So there would be a lot to gain from people using less water (Borgan, 2019). Water is a precious resource. So we have to handle it with care (Deboosere, 2023).

Water Consumption

A growing global population and economic shift towards more resource-intensive consumption patterns means an increase in global freshwater use for agriculture, industry and municipal uses. *(Ritchie & Roser, 2018).*

In Norway the average household consumption is 180 liter/person/day (Statistics Norway, 2022). This is almost twice as much compared to Denmark, where the average household consumption is 100 liters/person/day (Borgan, 2019). The difference in water consumption between Denmark and Norway is due to the difference in how water consumption is charged.

Saving water, even in a country like Norway where there will likely never be a Day Zero, is something that residents should learn to do (Borgan, 2019).

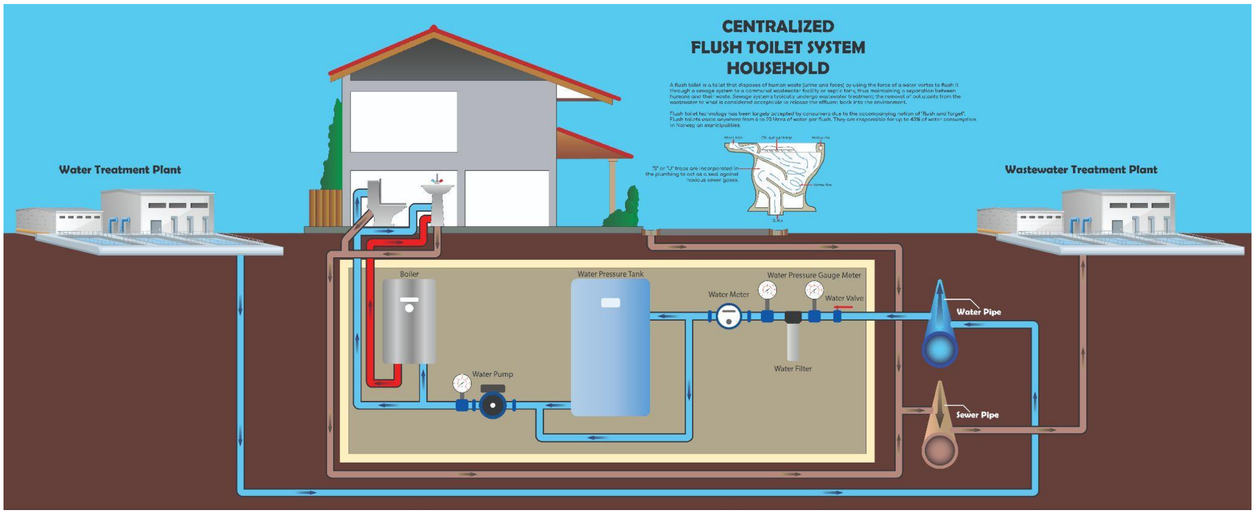
Lowering water consumption even in Norway is important, because tap water is first purified, then pumped to households and then treated again before being discharged into lakes, rivers or the ocean (Borgan, 2019). Providing clean tap water requires a lot of electricity, transport and not least, chemicals (Borgan, 2019).

Consumer

Antibiotics in livestock and pharmaceuticals that are ingested by humans have increased dramatically over the previous century and, subsequently, are found in blackwater
Literature reveals that antibiotics may enter the environment through waste streams and effluents as it is poorly metabolized in the wastewater treatment processes (Evgenieva Kelova, 2022).

Only a small part of the nutrient content of the food is retained by humans. Nitrogen and phosphorus excretion is at or near 100 % of the intake (Evgenieva Kelova, 2022). Currently, only a small part is recycled to land application, while the majority is disposed of as a waste driven to landfills or as an effluent discharged to water bodies. As a result, the nutrients and the organic matter create a burden to the receiving environments, while they are lost to soils and food production.
The recycling of human excreta not only provides reduction of waste and pollution but could also close the loop between agriculture and sanitation and could address future challenges for fertilizer availability and better nutrient management (Evgenieva Kelova, 2022).

Flush Toilet



A flush toilet is a toilet that disposes of human waste (urine and feces) by using the force of a water vortex to flush it through a sewage system to a communal wastewater facility or septic tank, thus maintaining a separation between humans and their waste. Sewage systems typically undergo wastewater treatment; the removal of pollutants from the wastewater to what is considered acceptable to release the effluent back into the environment.

Flush toilets waste anywhere from 6 to 20 liters of water per flush which makes it responsible for up to 40% of water consumption in Norwegian municipalities (Kaur Bhatti, 2021).

Flush toilets are the largest single user of water inside the home, turning potable water into wastewater that is expensive and resource-intensive to purify. The nutrients from wastewater systems are often discharged into water bodies where they contribute to nutrient pollution, harmful algal blooms, and other damaging ecological effects (Saner, 2019).

Flushing increases the velocity of the water and releases bioaerosols into the air resulting in the toilet serving as a mode for virus transmission (Kaur Bhatti, 2021). This is a sanitary disadvantage especially in light of the COVID pandemic.

Flush toilet technology has been largely accepted by consumers due to the accompanying notion of “flush and forget” (Kaur Bhatti, 2021). Where users are not concerned about the processing and treatment of blackwater once it is flushed down the toilet bowl because it is regarded as “waste” (Kaur Bhatti, 2021). However, we need to raise the question if it is still ethically responsible to waste fresh water, a vital biological resource required to sustain life for the mere purpose of flushing human waste out of residential spaces?

Foreign objects

The water force makes the flush toilet a forgiving and robust sanitation system. The downside of a forgiving and robust sanitation is the adoption of bad flushing behavior. The water pressure flushes feces but also foreign objects such as sanitary pads, medication, and oils down the drain. Wastewater treatment plants are left with the difficult task to remove these toxins and pollutants out of the water while dealing with the increasing effects of climate change and a growing population that push the capacity limits of the wastewater plants to provide safe and clean water.

Industry & Hospitals

Wastewater effluent from three Norwegian hospitals was shown to contain elevated loads of selected pharmaceuticals. Treated wastewater from four different wastewater treatment works was shown to contain elevated loads of selected pharmaceuticals and hormones (The Norwegian Environment Agency, 2016).

According to the wastewater treatment plant in Fredrikstad the residues of medication aren't monitored in the treated water (Solberg, 2023). Microplastics from food packaging are currently a more pressing issue for the Norwegian wastewater treatment plants (Solberg, 2023).

Pharmaceuticals & cosmetics sectors are jointly responsible for 92% of the toxic load in wastewaters in Europe (European Commission, 2022).

Black Water

Blackwater is counteractive to recovery of nutrients because the nutrients are diluted in water, which makes it harder to separate the low concentration of nutrients from the water. Water is a vital resource; biological life requires it to sustain itself; we cannot afford to waste fresh water for the mere purpose of flushing human waste out of residential spaces.

Aging Sewage Pipelines

A significant part of the Norwegian pipeline network is old as 1/5 of the pipeline network was built shortly after WW2 *(Steinberg, 2017)*. The sewage system in Norway is made of cement pipes that disintegrate over time and leak (Margel, 2023). The pipes that carry the blackwater are often in the same trench as the clean water pipes (Margel, 2023), increasing the risk of contamination during leakage or repairs which can cause illnesses such as gastroenteritis, diarrhea and vomiting.

The total length of sewage pipelines in Norway is 39 223,537 km (Statistics Norway, 2022). On a 3-year-average 0,67% of the total Norwegian wastewater pipeline system is renewed (Statistics Norway, 2022). The current rate of replacement of poor pipelines is so slow that it would take 145 years before all pipelines are improved to a satisfactory quality and the problem of contaminated drinking water and damage to pipelines is likely to increase in years to come due to precipitation, flooding and landslides as a result of climate change (Steinberg, 2017).

Failing to replace deteriorating pipelines causes on average, 30% of the water to leak out before it reaches the consumer. Which is much greater than in most comparable countries (United Nations, 2023).

Norwegian winters are especially hard on the sewage pipes because the warming and freezing of the ground leads to buildup of tension which causes damage to new and old pipes (Solberg, 2023).

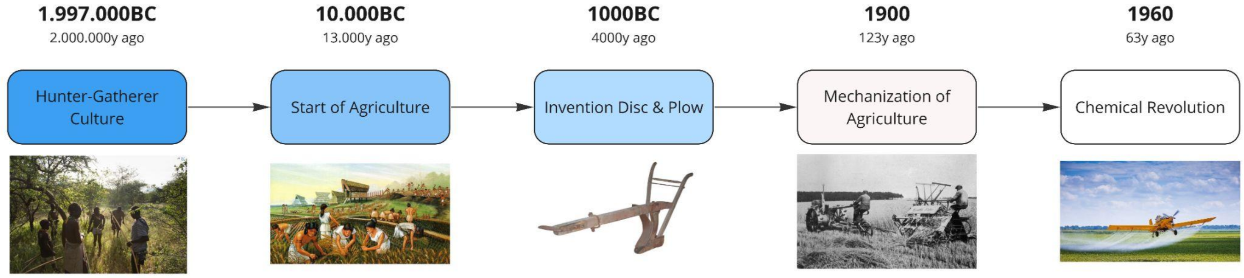
Monoculture

What monocultures produce is food empty of nutrients. Industrial farming practices have robbed the soil of its nutrients and created a huge demand for nitrogen fertilizer. (The Coinweaver, 2013)

Animal and human excreta had a major role in the development of agriculture in the past, but their role was lost with the development of the modern flush toilet and artificial fertilizers (Evgenieva Kelova, 2022). That way the nutrients were taken away from the soils, shifted to the water bodies and substituted with artificial fertilizers.
The intensive crop production which is sustaining the growing population today is unthinkable without the artificial sources of nitrogen, phosphorus and potassium. The use of artificial fertilizers, however, is linked with three burdens: these resources are finite, the risks of environmental degradation and pollution, and food, geopolitical and economic insecurities (Evgenieva Kelova, 2022) due to fluctuating availability and prices as we have recently experienced due to the war in Ukraine and the pandemic.

These resources are finite and their availability and price depend on geopolitics as we can see now with the war in Ukraine. The use of artificial fertilizer is associated with decreasing organic matter contents of soils and the deteriorating negative consequences. At the same time, wastewater treatment plants employ resources to remove the nitrogen and phosphorus before the effluent is discharged (Evgenieva Kelova, 2022). As Norway's wastewater treatment plants are struggling to keep up with the amount of inflow of wastewater and on top of that the stormwater during heavy precipitation, nitrogen and phosphorus are occasionally discharged without treatment and have resulted in the deterioration of multiple aquatic ecosystems.

History of Agriculture



To get a better understanding of how we have put ourselves into this situation we have to look back in history to see how agriculture has evolved and influenced human civilization over time.

Hunter Gatherer Culture

The first humans harvested food and foraged from the forests around them. They reaped the bounty of healthy soil without interacting with it (*“Dirt” - a New Documentary About Saving Our Soil*, 2022).

Start of Agriculture

When these natural sources dried up, we were forced to learn how to grow our own crops. Agriculture is considered the foundation of civilization. With a more stable lifestyle came an explosion in population (*“Dirt” - a New Documentary About Saving Our Soil*, 2022).

Invention Disc & Plow

We developed the disc and the plow, allowing farmers to break down more soil more quickly (*“Dirt” - a New Documentary About Saving Our Soil*, 2022).

Mechanization of Agriculture

Mechanization in the 1900’s made our tillage implements more efficient. Internal combustion engines freed us from relying on exhausted draft animals (*“Dirt” - a New Documentary About Saving Our Soil*, 2022).

Chemical Revolution

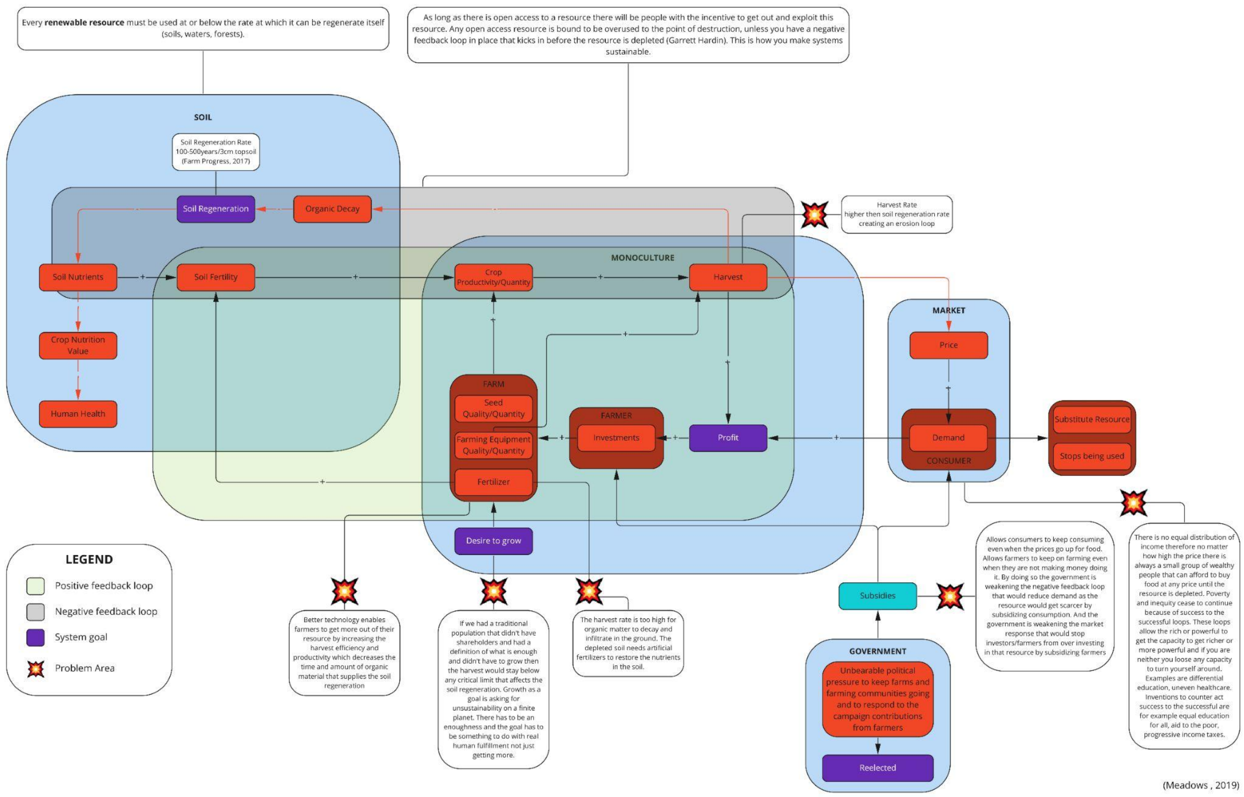
The 1960’s saw a chemical revolution. We applied petrochemicals to make soil more productive, faster (*“Dirt” - a New Documentary About Saving Our Soil*, 2022).

Insights gained from the History of Agriculture

All of this tillage, all of these chemicals, were applied to produce more from the soil, with little thought of how they affected the soil. With each turn of the plow and with change in the seasons, we have demanded more of our soil, like an athlete running a marathon for months on end, without sleep. After a century of mechanical and chemical tillage, the soil is exhausted. The microbial life and mycorrhizae are destroyed. Erosion is rampant and fertile lands are drying up.

Stocks & Flows Map

The stocks and flows map from Donella Meadows was used to understand and visualize how the agricultural system operates.



Unsustainable System

Soil is a renewable resource that means it doesn't regrow but rather renews itself and moves in cycles (Meadows , 2019). They go from one place to another, and often back where they started, again and again (Meadows , 2019).

A renewable resource like the soil must be used at or below the rate at which it can regenerate itself (Meadows , 2019). Meanwhile, it takes at least 100 years to build 3 cm of topsoil but it can take as many as 500 years. We live in a fast-paced society where quick fixes are often sought but building topsoil requires long-term solutions.

The stocks and flows map clearly illustrates that the positive feedback loop of increasing crop productivity, high harvest rate, more profit and bigger reinvestments reinforces the positive feedback loop. This system is creating an erosion loop weakening the feedback loop that regenerates topsoil.

The farmer interferes in the soil regeneration loop by removing organic matter that supplies the topsoil. As the harvest rate of the farmer is higher compared to the rate at which the soil can regenerate, the fertility of the soil enters a negative feedback loop. Which is a loop that counters a system that keeps trying to bring it into equilibrium (it is stopping the growth) (Meadows , 2019). As a result the depleted soil needs artificial fertilizers to restore the nutrients in the soil.

When this loop is sustained long enough it will reach a threshold at which point it becomes an erosion loop. Which means that we have taken down the system so far that when the more we attack the system, now instead of coming back and the soil regenerating itself it gets weaker and weaker. It is a loop that is taking the system down (Meadows , 2019).

This can only be prevented by reintroducing organic matter on the field not with the purpose of harvesting it but letting it decay to resupply the topsoil with mature organic matter or the farmer can lower his rate of harvesting which is an unrealistic solution considering the slow pace of soil regeneration.

As long as there is open access to a resource such as topsoil, there will be people with the incentive to get out and exploit this resource. Any open access resource is bound to be overused to the point of destruction, unless you have a negative feedback loop in place that kicks in before the resource is depleted (Garrett Hardin). This is how you ensure sustainable use of topsoil.

Technology

Better technology enables farmers to get more out of their resources by increasing the harvest efficiency and productivity which decreases the time and amount of organic material that supplies the soil regeneration.

Subsidies

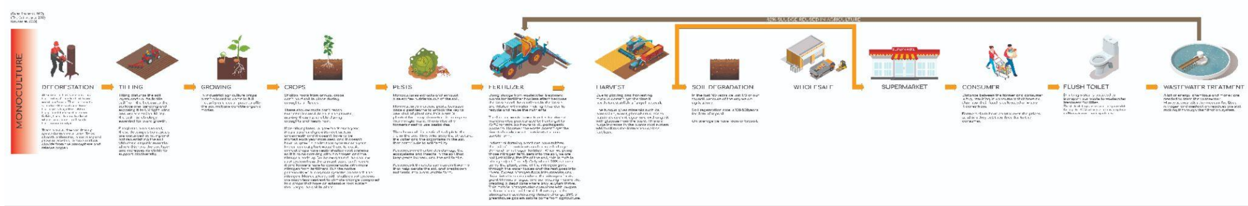
To make matters even worse subsidies allow consumers to keep consuming even when the prices go up for food. It Allows farmers to keep on farming even when they are not making money doing it. By doing so the government is weakening the negative feedback loop that would reduce consumer demand as the resource would get scarcer by subsidizing consumption. And the government is weakening the market response that would stop investors/farmers from over investing in that resource by subsidizing farmers.

The government does this because in order to be reelected they need to respond to the campaign contributions from farmers by keeping farms and farming communities going.

Purpose

The purpose of farms is to increase their yield which increases their profit. If the purpose of the farmer would be to be a good steward of the land by taking care of the health of the soil, the system would look completely different.

Monoculture Processor Map



Deforestation

Absence of trees means that the soil isn't protected from wind and rain. The tree roots stabilize the soil and hold the layers together. While they can't be used in crop fields, they should be kept where possible to absorb the carbon output.

Trees are cut down to free up space for monocultures. Trees absorb pollutants, protect topsoil, prevent erosion, remove carbon dioxide from the atmosphere and release oxygen.

Tilling

Tilling disturbs the soil layers and uplifts fertile soil from the bottom to the surface over aerating and exposing it to UV light, wind and water erosion. Killing the soil microbiology essential for plant growth.

Fungi rot plants to soil, these decomposition cycles are disturbed by tilling and not replenishing the soil with dead organic material which thickens the soil layer and increases its ability to support biodiversity.

Growing

In industrial agriculture crops aren't allowed to come to full maturity and decompose to offer the soil mature durable organic matter.

Crops

Shallow roots from annual crops don't hold soil in place during droughts or floods. These shallow roots can't reach nutrients located deep in the ground, making them vulnerable during droughts and heavy rain.

If we allow plants to grow back each year it can build and grow its root system underneath and it doesn't have to be started each year from seed and it doesn't have to grow its entire root system each year like an annual plant would have to do. As annual crops have really shallow root systems so if it rains carrying with it nitrogen and the nitrogen ends up 3m below ground the shallow root system from the annual plant can't reach it and farmers have to compensate with more nitrogen from fertilizers. But the native perennials with long root systems can reach the nitrogen. Monocultures with shallow root systems are much less resilient to climate change compared to crops that have an extensive root system that keeps the soil in place.

Pests

Monocultures extract and exhaust a select few nutrients out of the soil.

Monocultures increase pests, because once a pest learns to unlock the key to one kind of plant and this plant is planted for many kilometers it can open every single plant. This is also why farmers need to use pesticides.

The chemicals in pesticides deplete the life in the soil. They take away the structure, the water and the organisms in the soil that contribute to soil fertility.
Pesticides and herbicides damage the ecosystems and insects in the soil that keep pests incheck and the soil fertile. Pesticides kill insects such as earthworms that help aerate the soil and breakdown nutrients into plant usable form.

Fertilizer

Using sludge from wastewater treatment plants for fertilizer has less effect because the waste and the nutrients in the waste are diluted with water making it harder to recycle and reuse the nutrients.

The human waste in wastewater treatment plants is also pasteurized by heating it to 70 °C for min. 0.5 hours to kill pathogenic bacteria. However the waste doesn’t get the time to breakdown its nutrients to plant usable form.

Harvest

Due to plowing and harvesting mycelia doesn’t get the time it needs to establish a fungal network.
The fungus gives minerals such as potassium, water, phosphorus, micro nutrients and nitrogen and exchange it with glucose from the plant. This is a huge increase in the plant's root system which allows the farmer to use less fertilizer.

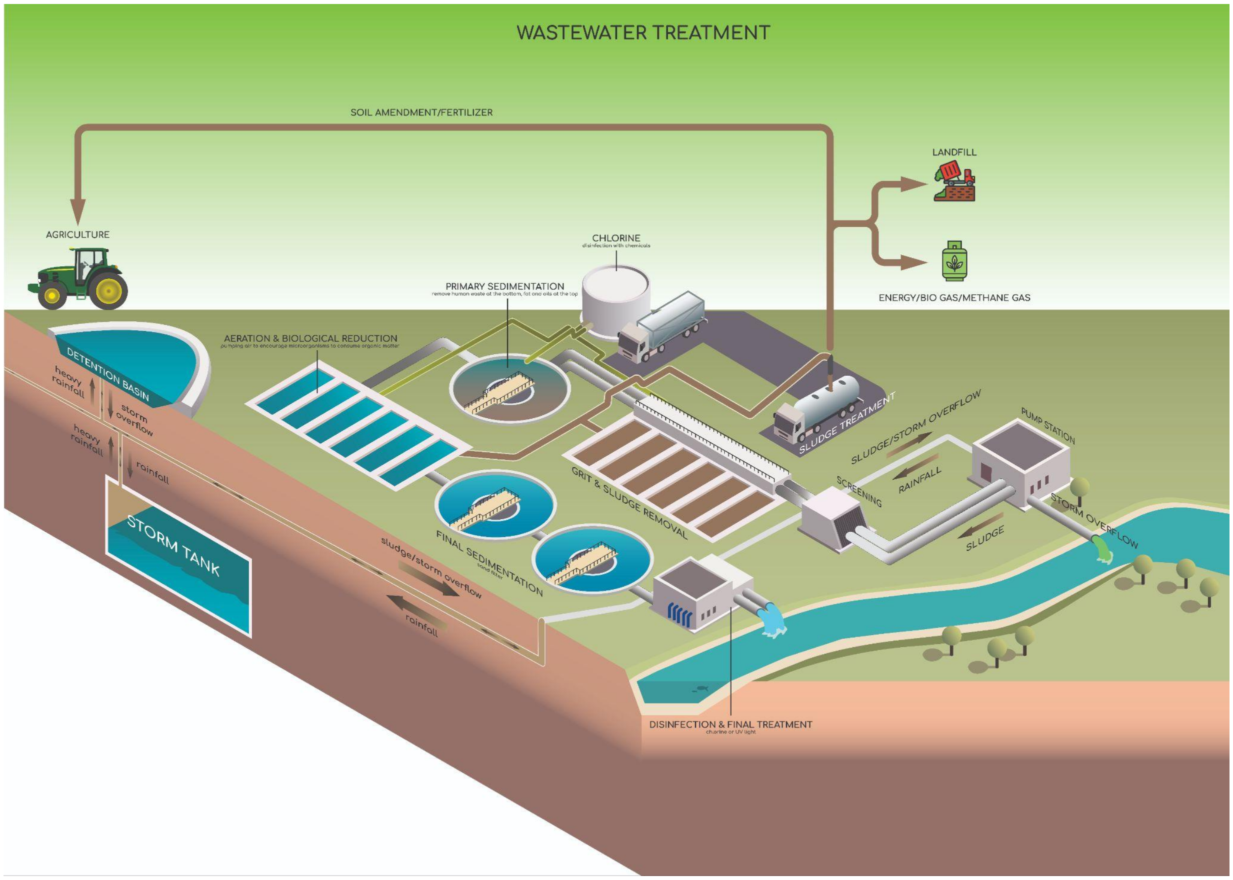
Soil Degradation

In the last 100 years we lost 1/3 of our topsoil because of the way we do agriculture. Soil regeneration rate is 100-500 years for 3 cm of topsoil. On average we have 15 cm of topsoil.

Consumer

Distance between the farmer and consumer is big, resulting in consumers that have no clue how their food is cultivated or where it comes from.
Farmers don’t have control over the prices at which they sell their food to the consumer.

Wastewater Treatment Plant



The force of the vortex in flush toilets allows consumers to get rid of objects that shouldn't be in the toilet in the first place such as sanitary pads, food scraps and tampons. A flush toilet system, although very robust and forgiving, facilitates bad flushing behavior and pollutes wastewater and makes the job of cleaning and treating wastewater harder for wastewater plants. Furthermore consumers aren't aware of the consequences of their action because the issue is dealt with for them by the wastewater treatment plants who are already struggling to keep up with the amount of wastewater that needs to be treated, resulting in the deterioration of multiple aquatic ecosystems.

Once wastewater reaches a treatment plant, it takes a lot of energy to clean it to a level where it can be discharged. Wastewater often contains a mix of food debris, shampoo, detergents — and urine and feces, of course. Consequently the water has to go through an extensive purification process to remove those substances.

Water utilities in Norway today are facing several challenges when it comes to providing good services to the customers and maintaining the quality of the urban water infrastructure. This includes (Reichborn, 2013): population growth, stricter government legislation, and aging infrastructure. As most of the sewage treatment plants in Norway don't remove nitrogen

(Solberg, 2023). Stricter regulation will be put in place in the future to prevent nitrogen feeding algae blooms.
The presence of medication residue isn't monitored by wastewater treatment plants (Solberg, 2023) as a result treated water from four different wastewater treatment works was shown to contain elevated loads of pharmaceuticals and hormones (The Norwegian Environment Agency, 2016).

Sludge

Sludge and dung are ineffective for agriculture use because it isn't mixed with carbon organic material that aids the combustion process. It doesn't get the time it needs to break down the waste to mature organic soil and nutrients that have been broken down to plant usable form. The maturing time also gets rid of any pathogens and medication residue. Now the dung from cows is applied untreated on the fields. It should be pasteurized (process of sterilization through heat treatment) just like wastewater treatment facilities do with the remaining sludge before it is applied on crop fields. This is important to prevent pathogens, medication residue and hormones from entering the waterways.

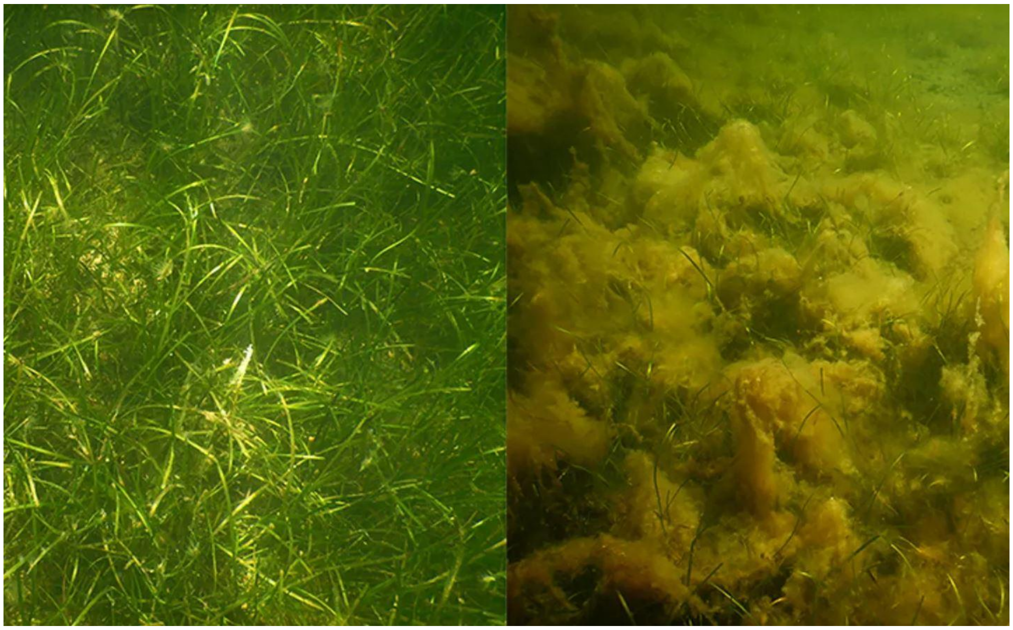
Unfortunately, more and more research indicates that large amounts of microplastic are re-introduced to soil with sludge *(Cydzik-Kwiatkowska et al., 2021).*

In Norway if sewage sludge is present it can't be used as a fertilizer for agriculture. The sludge from food waste can be used as a fertilizer in agriculture (Solberg, 2023).

Wastewater Treatment Future Challenges

Parts of today's water and sanitation systems in Norway are not adapted to extreme weather patterns due to climate change and a growing population. Increased precipitation, floods and rising sea levels will in the future be a challenge in many municipalities (United Nations, 2023), especially for wastewater treatment plants near shorelines (Solberg, 2023). In addition, precipitation and the risk of flooding and landslides due to climate change will increase the risk of damage to pipelines in the future.

Marine Life

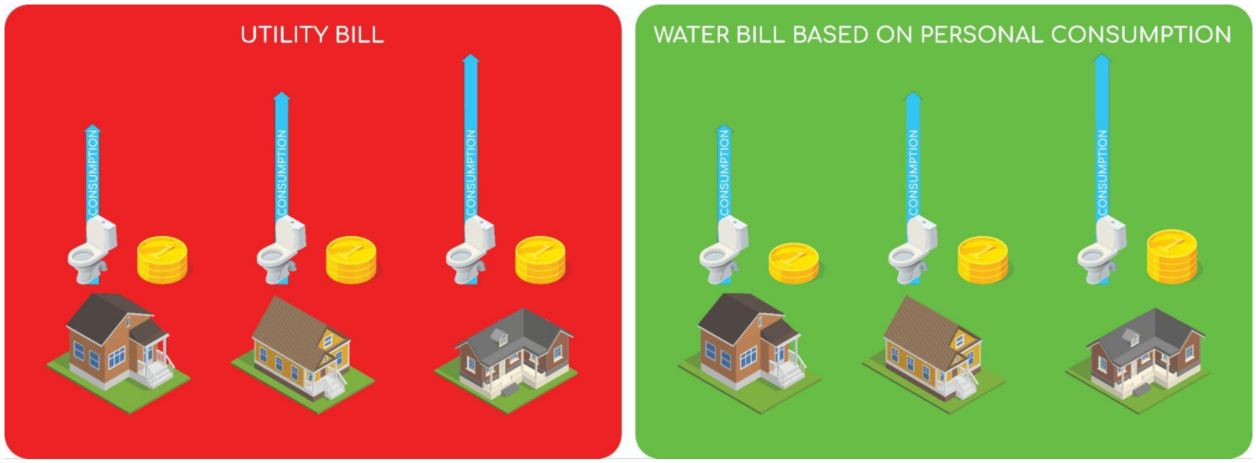


Even with the existing modern waste treatment plants that we have in Norway today, wastewater isn’t cleaned sufficiantly. Mobile nitrogen from agriculture is still leaking and collecting at the bottom of the Oslo fjord feeding algae blooms, suffocating marine life and destroying kelp forests and eelgrasses (Miljødirektoratet, 2022). Also hormones from contraception pills enter the Oslo fjord neutering marine life. This goes to show that even the advanced wastewater treatment plants in Norway aren’t able to clean the water sufficiently before releasing it back in the ocean. These issues aren’t limited to Norway, they can be found along many coastal areas in developed countries (Margel, 2023).

Medications for the treatment of mental illness not only influence the behavior of humans, but also that of fish. For example, fish and small crustaceans become more aggressive or more passive, according to the research. This affects the chances of survival of marine life. (Lauwerier, 2023)

Estrogen in birth control pills has a negative impact on fish. They develop problems with procreation (Lina Nikoleris, 2016).
The mobile nitrogen from agriculture also combines with oxygen to form nitrous oxide which floats up to the atmosphere accelerating climate change. 25% Of greenhouse gas emissions are coming from agriculture (The Coinweaver, 2013).

Economy



Denmark has a lower water consumption per capita compared to Norway, because there is a difference in how the monthly water bill is calculated. In Denmark it is calculated based on your personal consumption. In Norway a utility bill is paid which means that the cost for water consumption and wastewater treatment is a shared cost which accounts for the municipality's average water consumption (Margel, 2023). Norwegian's personal water consumption doesn't reflect directly in their utility bill thus citizens have no notion of whether they consume water economically or not. This proves that the economy and the environment are intertwined.

Norwegians are very conscious now about how much electricity they use, and they have all sorts of apps for covering how much electricity they consume daily in order to keep costs down (Margel, 2023).
The interesting thing is that the cleaning of the water uses a lot of electricity. Our monthly utility bills from the municipality would be greatly decreased if we used less water (Margel, 2023).

Resources

Investments

A single Norwegian household pays on average 9.000 NOK in total yearly fees for water and wastewater services (Norks Vann, 2018).
To avoid sending the bill to future generations, many municipalities demand to increase the fees due to future challenges such as: increasing quality demands for drinking water, wastewater and sludge, climate change adaptation, an increasing population and urbanization and the need of higher renewal rate for the water mains and sewers (Norks Vann, 2018).

Chemicals

The cleaning of wastewater from our homes is not only the economic cost but also the chemicals used to treat the wastewater and the CO_2 and methane released through the use of chemicals to clean the wastewater that pose an environmental threat. Each wastewater cleaning station also uses huge trucks to freight the chemicals and all that's needed back and forth. Some countries don't recommend you drink the water not because of waste residues but because they use a high degree of chlorine to treat wastewater which can be harmful over time (Margel, 2023).

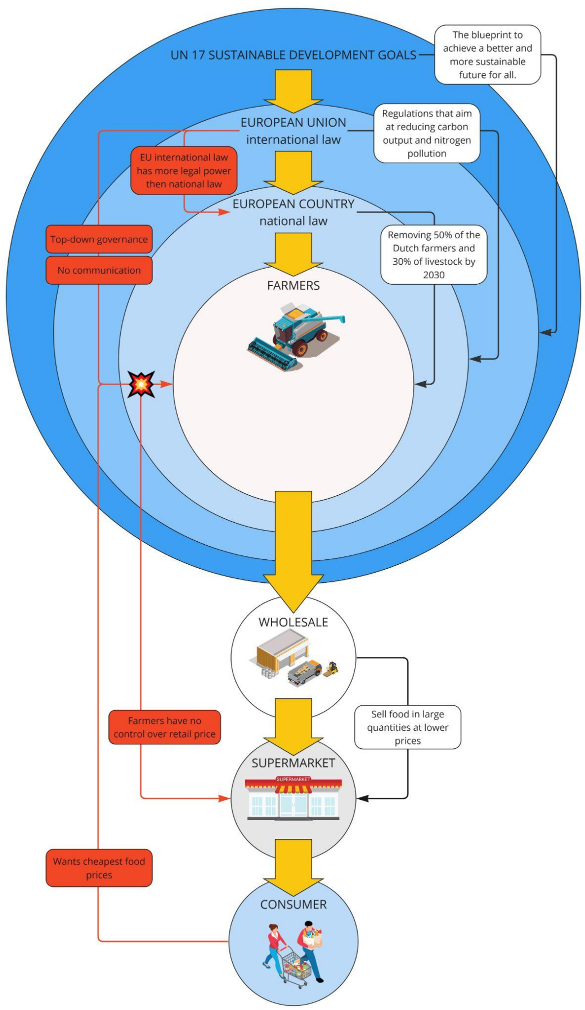
Electricity

In 2014, Norwegian municipalities spent more than NOK 400 million on electricity for water and sewage. This represented more than one-tenth of the total electricity consumption of the municipalities (Borgan, 2019).

Infrastructure

The value of the water and wastewater infrastructure in Norway today is calculated to be 1.300 billion NOK. The municipal and private pipes accounts for approximately 90 % of this value (Norks Vann, 2018).
Norway has 47 000 km of main drinking water supply pipes and 50 000 km of wastewater pipes (Reichborn, 2013).

Legislation



The Dutch farmer protests against new environmental regulations on nitrogen pollution is a situation many countries can learn from. Because other European countries are in a similar situation and in spite of its small size, the Netherlands is the world's 2nd largest agricultural exporter (after the United States). Needless to say, Dutch farmers know how to do their job and the position that Dutch farmers find themselves in could easily happen to farmers in other countries as well.

Environmentalist activists have taken the Dutch government to court to force them to comply with European Union regulations that are aimed at reducing carbon output and nitrogen pollution to protect nature and preserve the landscapes in the Netherlands (B Peterson, 2023).
The environmental policies implemented in European countries by the European Union are based on the UN sustainable development goals. The sustainable development goals are all positive goals, but they are converted into top-down policies that are implemented by force. The laws in any country in the European Union aren't made in that country but they come from the European Union. This leaves a huge gap between the citizens and the laws they must abide by. Moreover, any EU international law has more legal power than national law in an EU country. The question can be asked how the common good and democracy can exist under the influence of such a political system? (B Peterson, 2023).
Dutch Farmers use satellite technology in the machines that distribute nitrogen fertilizer to make sure it's never overused, and farmers have strived diligently for the last six decades to be hyper efficient with fertilizer use because it is expensive. The Dutch government's approach to reduce nitrogen pollution remains: removing 50% of the Dutch farmers and 30% of livestock by 2030 (B Peterson, 2023).
As a result, the Dutch farmers feel pressured by their government to follow strict European Union regulations and so far, negotiations between the farmers and the Dutch government haven't led to substantial change for the farmers as a result the farmers are pushed to desperation which has resulted in an increase of suicide rate of Dutch farmers (B Peterson, 2023).

Legislation Limitations

As we move towards international governance which is necessary to some degree because nations have to communicate, the distance in terms of communication between people at the local level such as the Dutch farmers and those that govern them is so great that there is no communication, there is just top-down governance (B Peterson, 2023).

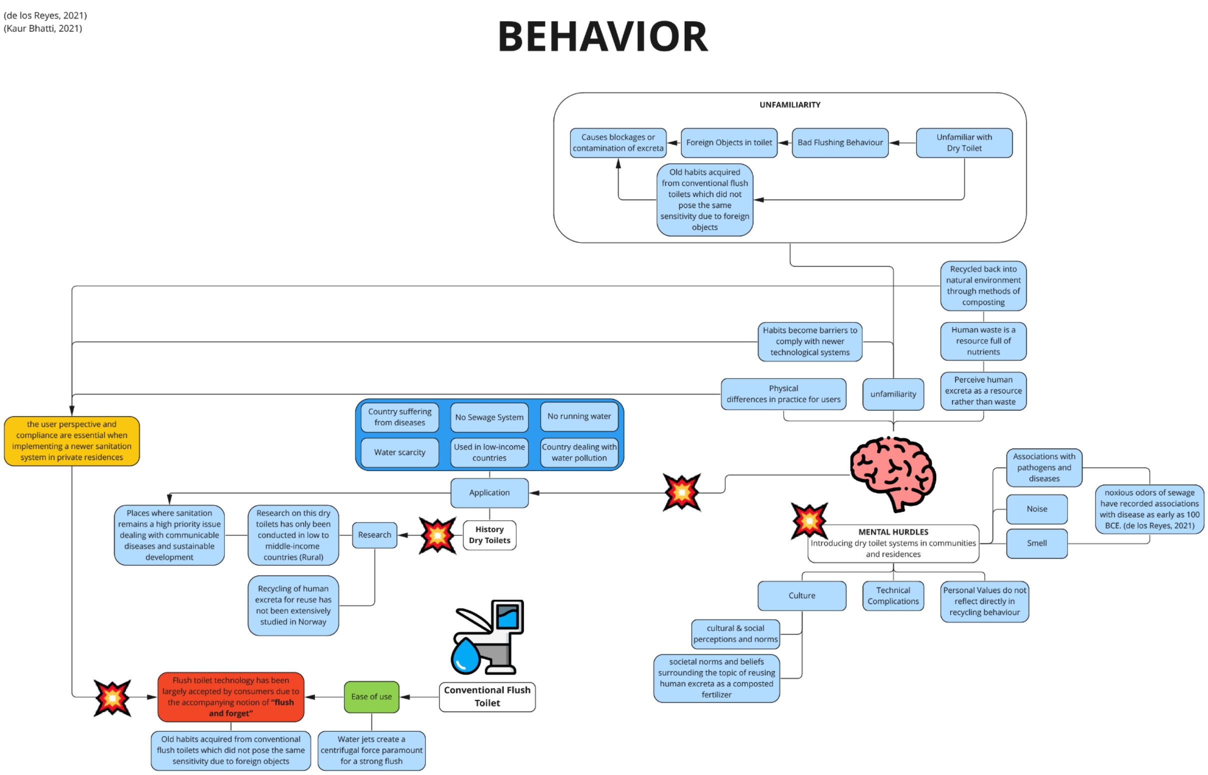
The principle of the primacy of European Union (EU) law is based on the idea that where a conflict arises between an aspect of EU law and an aspect of law in an EU Member State (national law), EU law will prevail (EUR-Lex, 2023).

Farmers are stuck between the regulations that they must follow pushed by politicians and the consumer that wants the lowest price possible. Farmers must be good at business.

Politicians have no long-term vision because the Dutch government doesn't consider how the lack of livestock and farmers will affect the rest of the Dutch food supply chain (B Peterson, 2023).

Interestingly from a systemic point of view the situation in the Netherlands is a perfect demonstration on how system behavior comes out of the system, its interrelationships, and goals not the elements or the people (Meadows, 2019), in this case the farmers. The parts acting within a system are usually interchangeable, you can take out one (the farmers) and put in another and the system still behaves the same way (Meadows, 2019).

Key Barriers to Dry Toilet System Acceptance

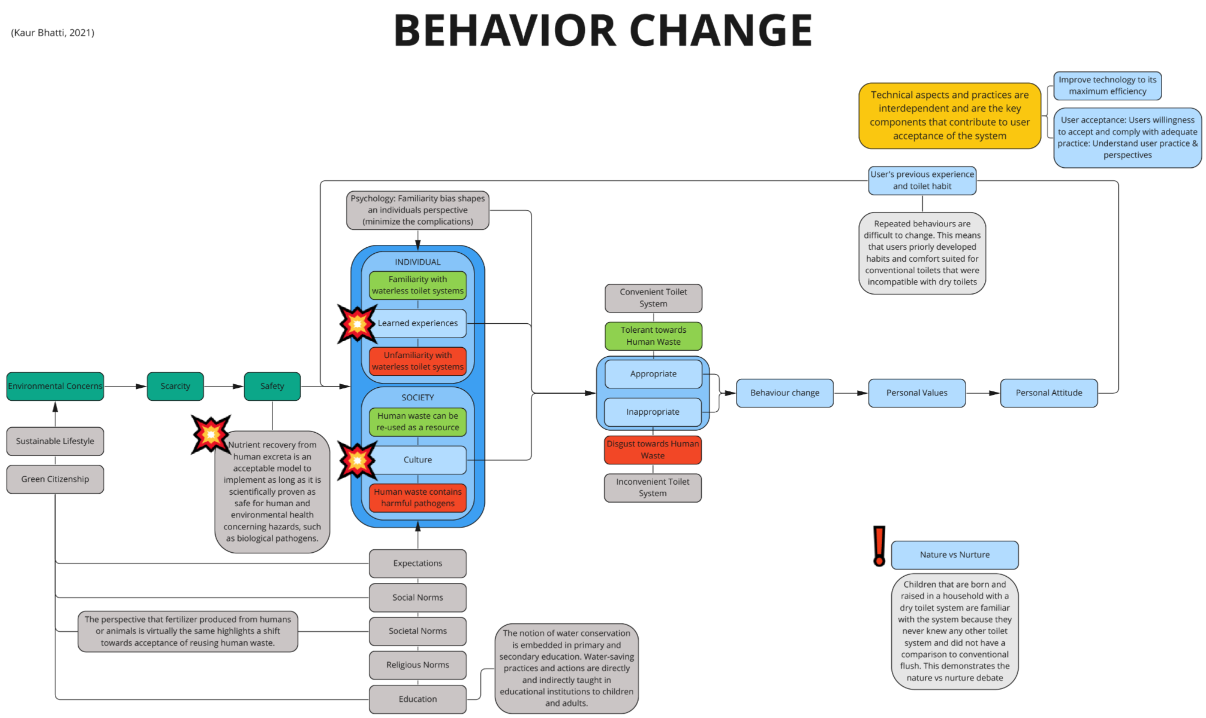


Some of the main barriers to dry toilet systems and nutrient recovery are:

- Opposing cultural and societal perceptions
- Unfamiliarity with the dry toilet sanitation system
- Recycling human waste is deemed to be difficult or inconvenient
- Being confronted with your own waste
- Perceived association between bad smells and diseases
- Excreta can contain harmful pathogens, therefore humans have a survival instinct that creates a natural repulsion towards feces.
- Old habits become barriers to comply with other toilet systems
- Dry toilets are mainly used in rural areas and underdeveloped countries

Nutrient recovery from human excreta is an acceptable model to implement as long as it is scientifically proven as safe for human and environmental health concerning hazards, such as biological pathogens (Kaur Bhatti, 2021).

Overcome Mental Hurdles



In order to change people's behavior towards dry toilets, the most important is to ensure that the toilet system is scientifically proven as safe for human and environmental health concerning hazards, such as biological pathogens.

Psychology, evolutionary adaptations, or religious norms and practices are important and relevant approaches to understand peoples' inherent and learned feelings towards human excreta and practices associated with the handling of human excreta (Kaur Bhatti, 2021).

Another effective way to get compliance is by making the culture more accepting toward the use of dry toilets and nutrient recovery. By slowly educating and exposing people to positive individual learning experiences. This will allow societal norms and perceptions to slowly shift.

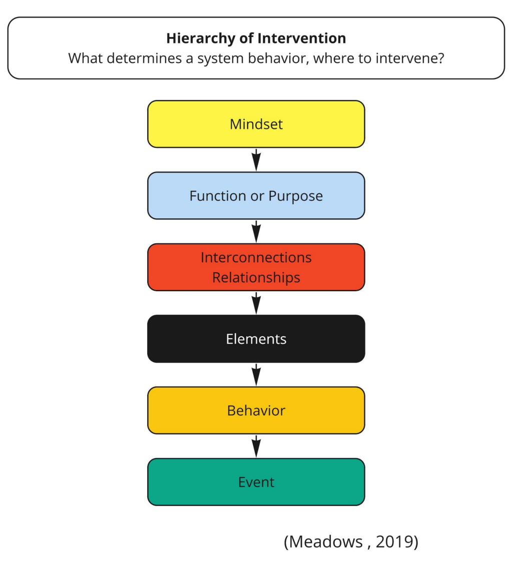
Pilot Project Examples

In 2018 when South Africa was facing a water crisis, the Water Research Committee in South Africa invited Cinderella (incinerating toilets) to step in, in order to provide sanitation not only in the slum areas, but also for the upper middle class (Margel, 2023). The Cinderella toilets were welcomed among those living in slums and the lower middle class. But the rich upper class was hesitant to go from a fully comfortable flush toilet to a toilet where you need to put a bowl liner and that requires a change in your habits (Margel, 2023).

Using deductive reasoning it can be assumed that there is a correlation between the social class and wealth of a person and their willingness to change their habits, in that regard Norway can be compared to South Africa (Margel, 2023).
The government in South Africa wanted a backup toilet system that offered a comfortable solution in case there was a low water table or trouble with access to water (Margel, 2023). According to Trude changes are only going to be made if we as consumers are willing to change our habits.

Cinderella also collaborated with the government In Hawaii because they had issues with open air cesspools (collector for toilet wastewater) leaking 208197 liters of wastewater daily into the groundwater that provides drinking water and into the ocean, killing off the coral reef (Margel, 2023).
Cinderella helped the homeowners connected to the cesspools to replace the flush toilet with a Cinderella incinerating toilet to avoid health issues and further contamination of the water. In Hawaii the homeowners were very happy to make the change because they were very conscious of the environmental challenge and the health issues on the islands (Margel, 2023).
Changing habits and societal norms all depends on the consumer outlook and the government support (Margel, 2023).
Norway gives off the impression of having a boundless amount of water and no environmental challenges (Margel, 2023). Therefore no one really thinks about the issues. Until the government works harder on a campaign to provide consumers with the true knowledge about the adverse effects of flush toilets and the sewer system on the environment the chances of generating change in Norway are slim.

Solutions



The hierarchy of intervention by Donella Meadows was used to structure the solutions according to their level of influence on the system.

Mindset

To give ecological sanitation any chance, awareness needs to be created about the “One Health” approach. This will make people aware about how human health is dependent on healthy soil and clean water sources. We need to stop seeing ourselves as disconnected and in control of nature but rather being part of nature. This helps with recognizing that human waste shouldn’t be perceived as waste but as a resource.

A change in mindset is needed to change people's relationship with water. Many people are unaware how water use affects the environment (Borgan, 2019). Norwegians are more concerned with whether our tap water is safe to drink, than if we waste it (Borgan, 2019) this is a culture that needs changing.

To create sustainable long-term solutions we need to revisit what value and purpose water has in our lives and think about how we can preserve that value in the future by redesigning our relation to water, how we use it, what we use it for and how we take care of it. As issues linked to water are often invisible, campaigns to increase people's understanding of the value of tap water will prove to be important.

Normalizing a culture where returning nutrients back to the soil and food production is evident will prove to be the most important for nutrient cycling, soil quality and successfully integrating dry toilets in urban areas.

Change the way we look at toilets from an object that gets rid of our waste to an object that collects, sorts and recycles waste.
Change of culture where reuse of feces is more accepted by the general public this can be encouraged by doing more research about waste treatment methods and developing better ecological toilet systems.
Research and policy attention should shift from pollutant removal (end of pipe solution) to resource-oriented management (preventive solution at the source). To envision human excreta as a resource is a way to off-set some of the fertilizer needs and reduce the pressure of nutrient pollution to freshwater and marine environments (Evgenieva Kelova, 2022).

The economy, environment and human health are interconnected and shouldn't be viewed as separate entities. One can stimulate the other.

To envision human excreta as a resource is a way to off-set some of the fertilizer needs and reduce the pressure of nutrient pollution to freshwater and marine environments (Evgenieva Kelova, 2022).
Society needs to learn to see the soil as more than just a medium to be manipulated, but as an ecosystem to be nurtured (*"Dirt" - a New Documentary About Saving Our Soil*, 2022).

Farmers should become stewards of the land. Their purpose is to preserve the topsoil on which life depends on. The ground is full of life and life-giving nutrients. Farmers should learn ways to conserve and make the soil a hospitable place for life and welcoming the tiny organisms that make this ecosystem so vibrant. We need to learn to see the soil as more than just a medium to be manipulated, but as an ecosystem to be nurtured.

Function or Purpose

The purpose of farming shouldn't be profit or generating the biggest yield. The purpose of farming should be to strive to be the best stewards of the land to protect the ecological ecosystems farming depends on allowing farmers to grow big yields, bigger profits and nutritious food.

The purpose of toilets shouldn't be to flush away waste but to separate the waste from the source and reintroduce nutrients back to the environment where they came from.

Interconnections, Relationships & Information Flow

In order to safeguard sustainable use of renewable resources, negative feedback loops need to be in place. The negative feedback loop kicks in before the resource is depleted (Garrett Hardin).

Communication and educating the population about the benefits of recycling waste instead of discarding it into the landfill.

Exclusive partnership with one waste management company eases the administrative burden for cities and municipalities. Making it easier for the city to align and collaborate with a waste management company on long term goals (CNBC, 2018) to decrease waste disposal or lower water consumption.

Open conversation between policymakers and farmers need to be stimulated. Instead of top-down governing, grassroots change from the bottom up is a better approach. Welcoming pilot projects that aim at testing and developing new methods of farming. The motivation for change should be initiated from the bottom not the top.

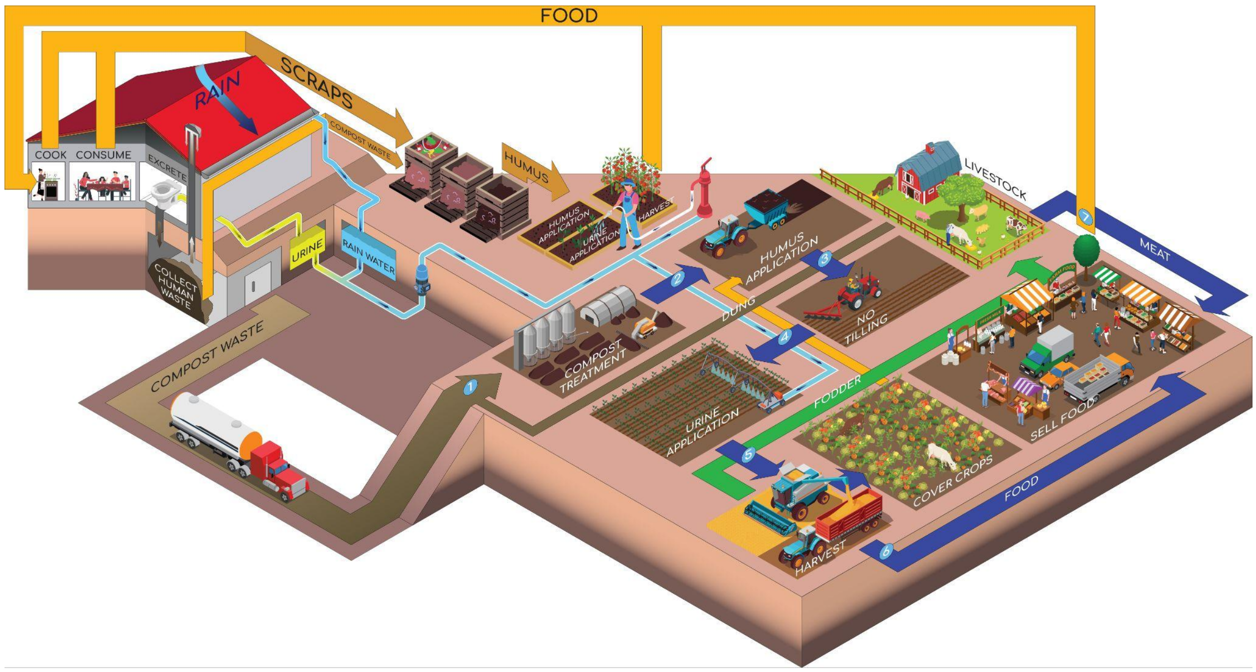
The monthly utility bill is calculated based on your personal consumption. The bill isn't an average calculation of the municipality's water consumption, rather the bill is a direct reflection of your own consumption. This confronts people with their own consumption behavior and encourages them to take responsibility in their own hands. This also means all Norwegian homes will have to install a water meter so the municipality can check how much a citizen needs to pay for their monthly bill but it also allows the citizen to check on how much they are consuming and to adapt their consumption behavior based on real time data.

To motivate people to transition to dry toilets it is estimated that they can cut their sewer fees by 50% (Petter D. Jenssen).

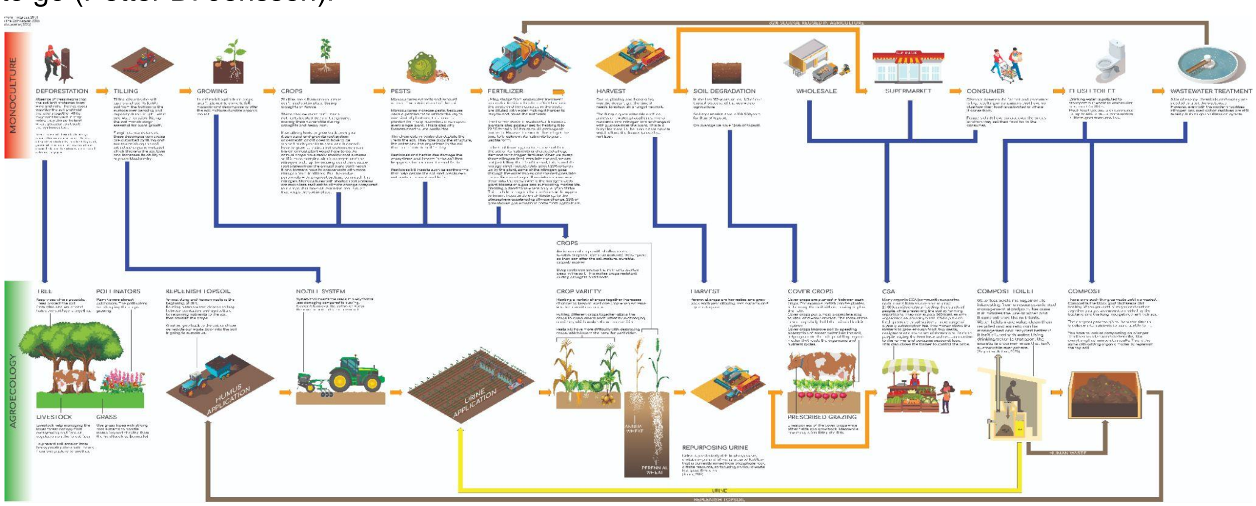
To encourage composting, recycling and composting needs to be mandatory. Trash collection rates should be set much higher than recycling and composting rates to encourage composting behavior. Collection rates for residents and businesses should be determined by the volume of waste. Businesses should receive discounts for using compost or recycling bins and penalized if recyclables or food scraps end up in the trash. Economy and environment need to reinforce each other instead of treating them as separate entities (CNBC, 2018).

Elements

Regenerative Agriculture



Manual crop farming is more productive as plants can be planted closer together and the fields are more efficiently used. With manual crop farming you can yield 50 kg/m3 of potatoes compared to 35 kg/m3 with industrial farming (Petter D. Jenssen). 70% of food in the world is produced on small fields, not industrial fields. Transitioning to regenerative agriculture is the way to go (Petter D. Jenssen).



Tree

Keep trees where possible. Trees protect the soil from wind and water and hold the soil layers together.

Livestock

Livestock help manage the lower forest canopy from overgrowing and feed on vegetation on the forest floor. To prevent soil erosion from heavy grazing the cattle moves from one pasture to another.

Grass

Use grass types with strong root systems to handle trampling and chewing from the herd (such as Bermuda)

Pollinators

Plant flowers that attract pollinators. The pollinators help keep the crops growing.

Replenish Topsoil

Animal dung and human waste is the beginning of dirt. Reusing human waste closes the loop between sanitation and agriculture by returning nutrients to the soil that nourish the crops.

What we give back to the soil and how we recycle our waste back into the soil is going to sustain us.

No-Till System

System that inserts the seeds in a way that is less damaging compared to plowing. It doesn’t turn over the soil which keeps the mycelia and soil structure intact.

Crops

Avoid annual crops with shallow roots to allow crops to reach full maturity, decompose so they can offer the soil mature, durable, organic matter. Deep roots can access the nutrients located deep in the soil. This makes crops resistant during droughts and floods.

Crop Variety

Planting a variety of crops together increases chances to keep at least one crop when extreme weather conditions occur.
Putting different crops together allows the crops to complement each other by exchanging nutrients, which makes them more resilient.
Pests will have more difficulty with destroying crops. which lowers the need for pesticides.

Harvest

Perennial crops are harvested and grow back each year allowing root systems and mycelia to grow.

Cover Crops

Cover crops are planted in between cash crops. For example radish can be planted to break up the soil without having to plow the field. Cover crops put almost a complete stop to wind and water erosion. The roots of the cover crops help hold the soil and lock it in place. Cover crops improve soil by speeding absorption of excess water into the soil, helping aerate the soil, providing organic matter that feeds the organisms and nutrient cycles.

Prescribed Grazing

Livestock eat the cover crops while other fields can grow back. Meanwhile cow dung is fertilizing the field.

CSA

The farmer-consumer relationship can be improved by introducing CSA's (community supported agriculture) which allow farmers to grow 20 000euros/acre/year feeding thousands of people, while preserving the soil by farming organically. They can supply 500 families with vegetables on a weekly basis. CSA's provide fresh produce to subscribers in exchange of a yearly subscription fee. This money allows the farmers to grow enough food, buy seeds, equipment and take care of themselves. And the consumer has a direct connection with the farmer and consumes seasonal food. This also allows the farmer to control the price (The Coinweaver, 2013).

Dry Toilet

Waterless waste management is interesting from a resource-oriented management standpoint because it minimizes the use of water and it concentrates the nutrients. Water holds more value clean than recycled and excreta can be managed and recycled better if it isn't diluted with water. Using drinking water to transport the excreta is a convenience that isn't sustainable everywhere. (Evgenieva Kelova, 2022)
Urine is particularly rich in phosphorus, a vital component of manufactured fertilizer that is currently mined from phosphate rock, a finite resource, so focusing on reusing liquid waste is a good first step. (Saner, 2019)

Compost

There is no such thing as waste until it's wasted. Compost is the black gold that keeps dirt healthy. When you add nitrogen and carbon together you get a combustion, aided by the bacteria and the fungi you get nutrient rich soil.
The compost process gives the waste time to breakdown its nutrients to plant usable form. You

have to look at composting on a longer timeline to understand the benefits. Not everything has immediate results. This is the same with adding organic matter to replenish the topsoil.

Water

36,6% Of Norwegian households have installed a water meter in 2021 (Statistics Norway, 2022). That means 63,4% of Norwegian households are unaware of their water consumption and they have no data that they can use to learn what steps they can take to save water.

Sanitation

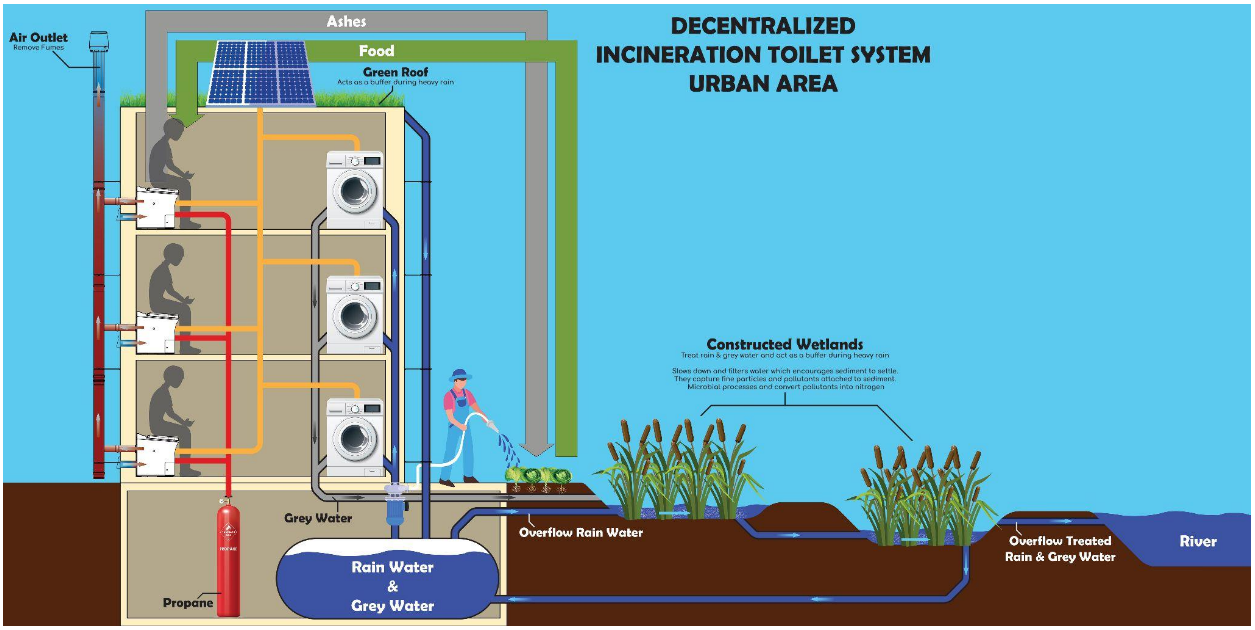
Ecological sanitation systems should be designed with user friendliness in mind to ensure a short learning curve and integrate the toilet system in the user's daily life to the point that it becomes second nature.
Usually a new toilet system demands a change of habit, just as recycling of trash did in the past. As people became aware that recycling trash is good for the environment and a responsible way to run their homes they adopted the new habits over time (Margel, 2023). The same change of mindset is needed to get the public acceptance to successfully integrate ecological sanitation in homes and urban areas (Margel, 2023) because people realize how they contribute to a cleaner environment and healthier soil by using a toilet system that uses no water and returns nutrients to the earth.

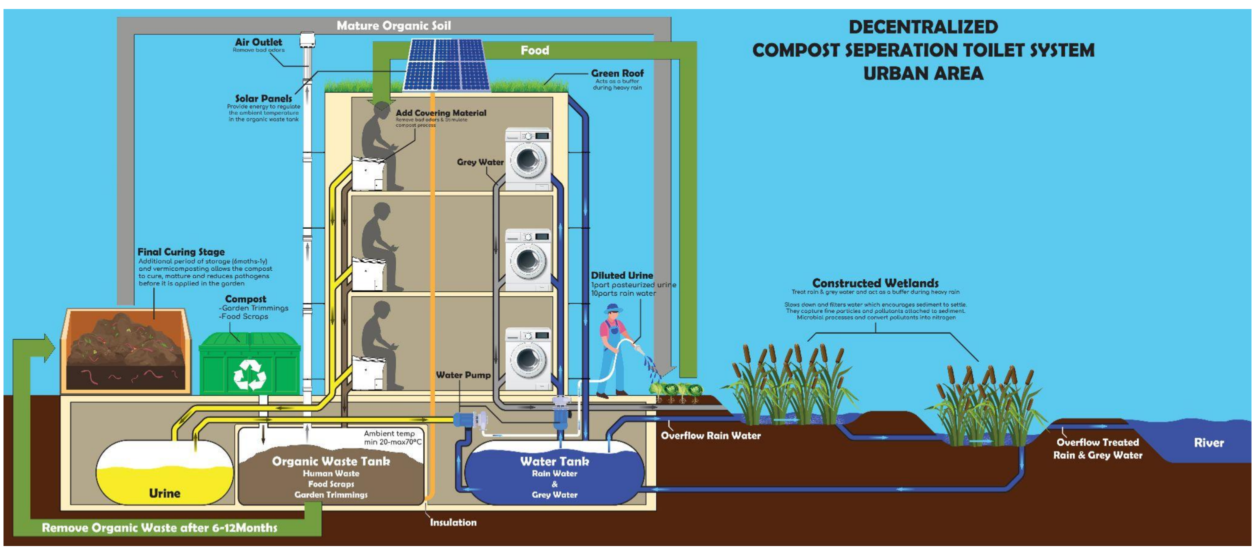
To truly strive for sustainable living, nutrient recycling in addition to the reduction of freshwater use and consumption is fundamental (Kaur Bhatti, 2021).

Next I have illustrated 10 different integration solutions in urban and rural areas both centralized or decentralized for the Klaro, diverting compost toilets and incinerating toilets.

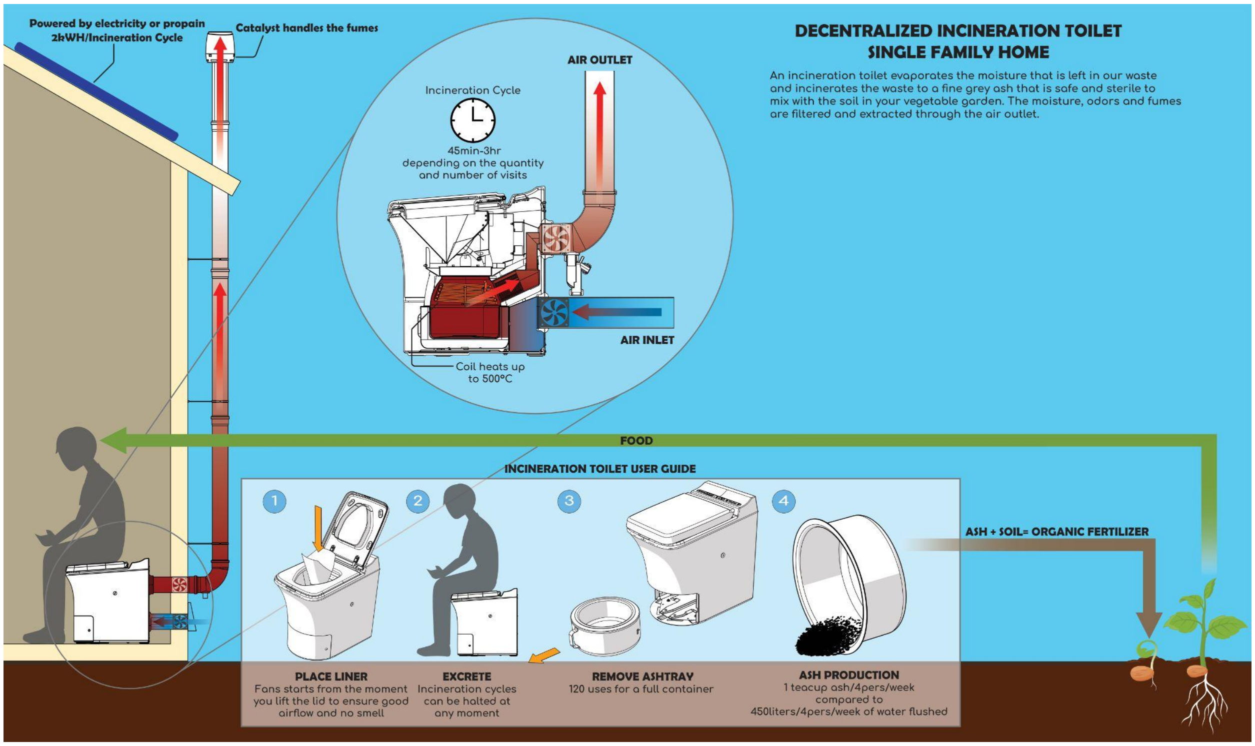
Decentralized

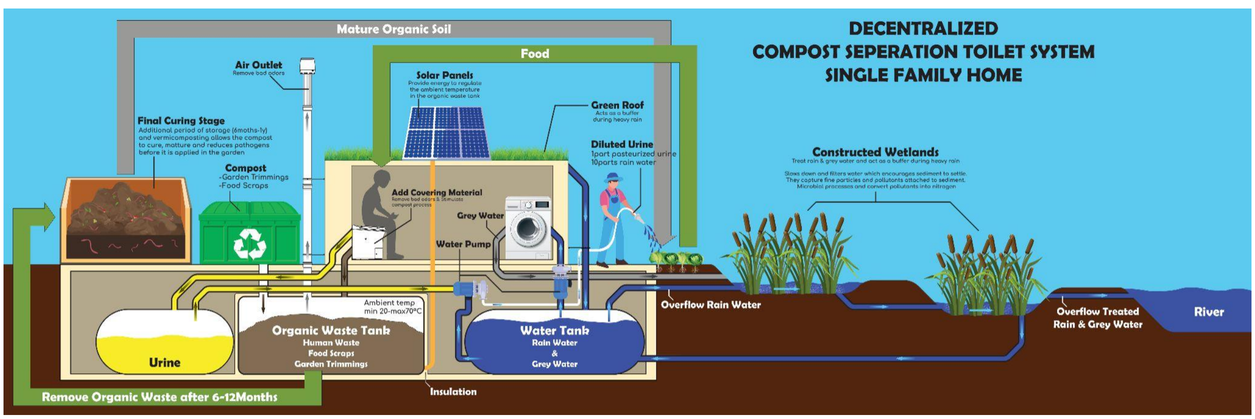
Urban





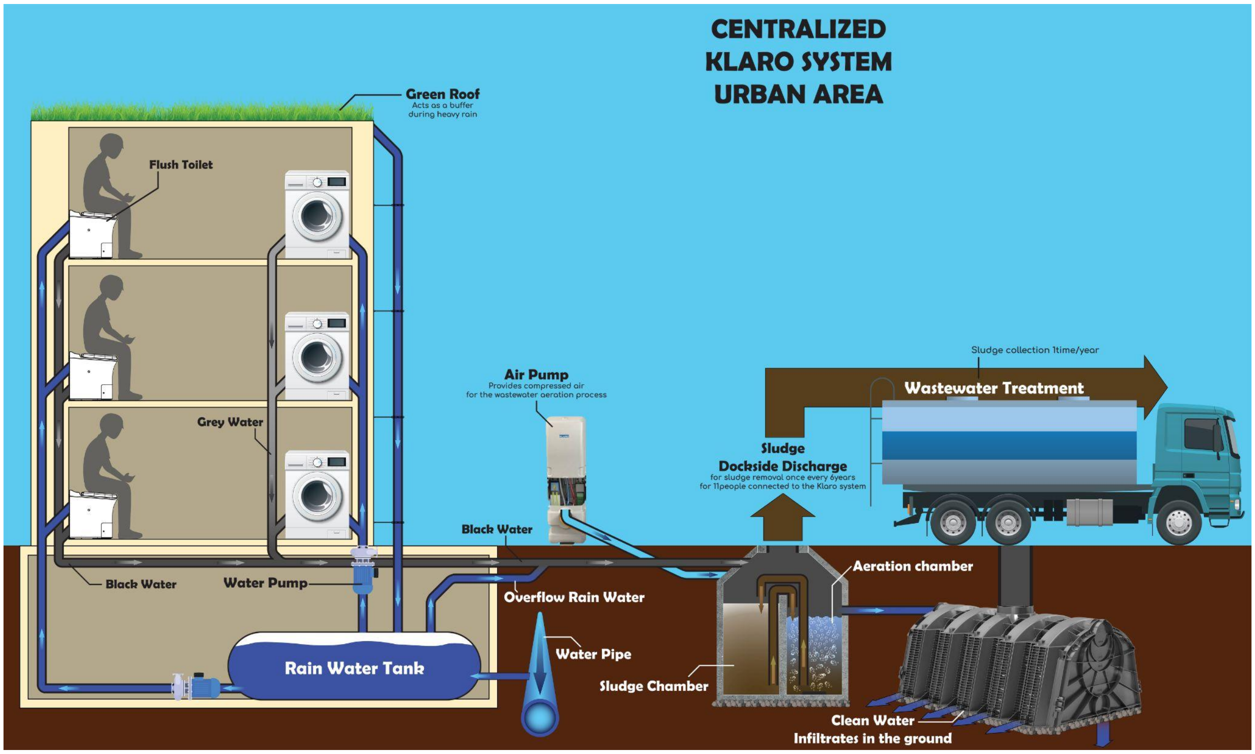
Single Family Home

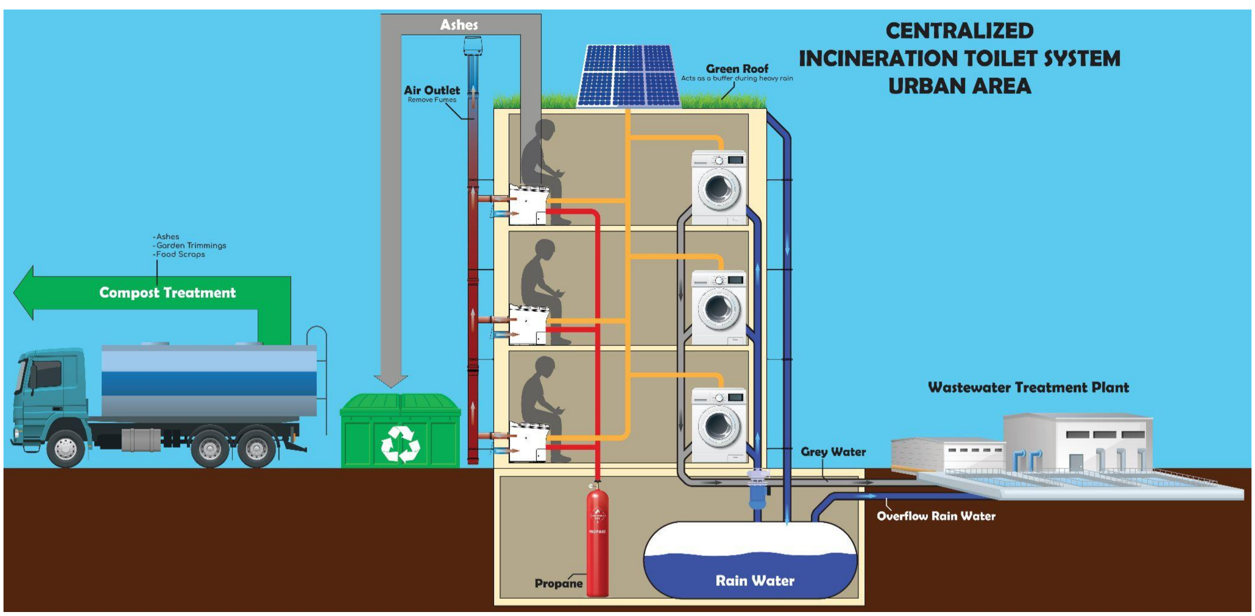


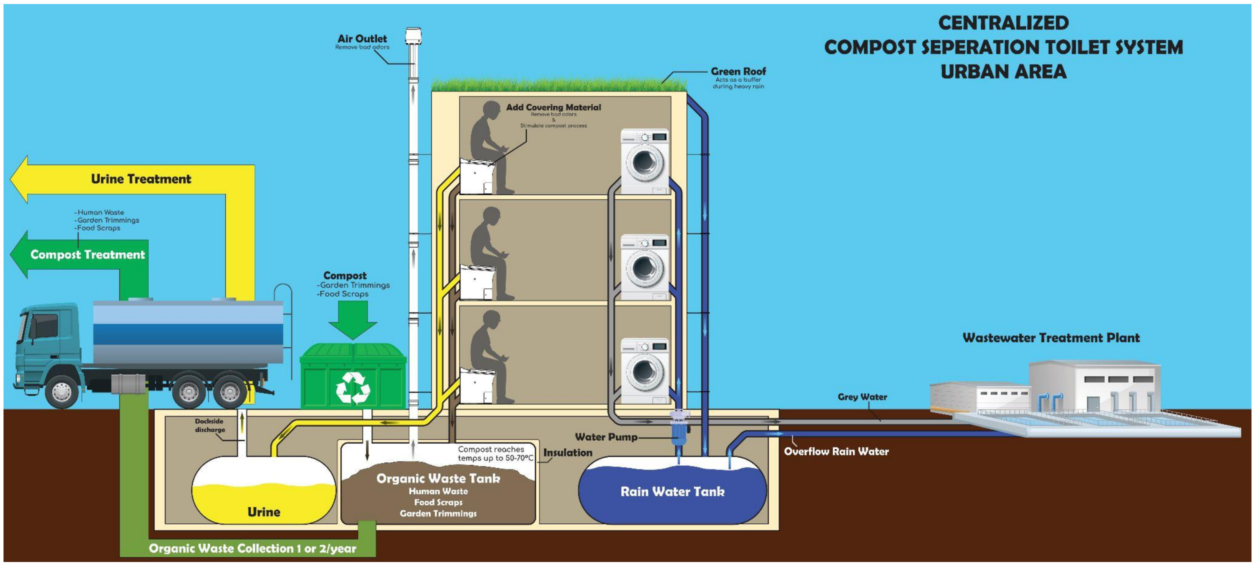


Centralized

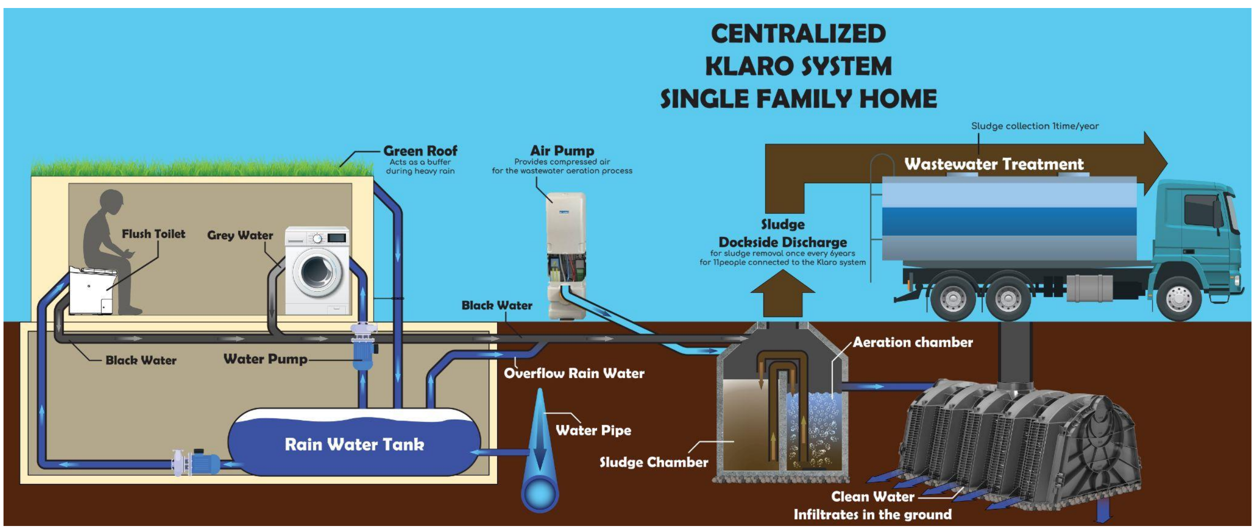
Urban

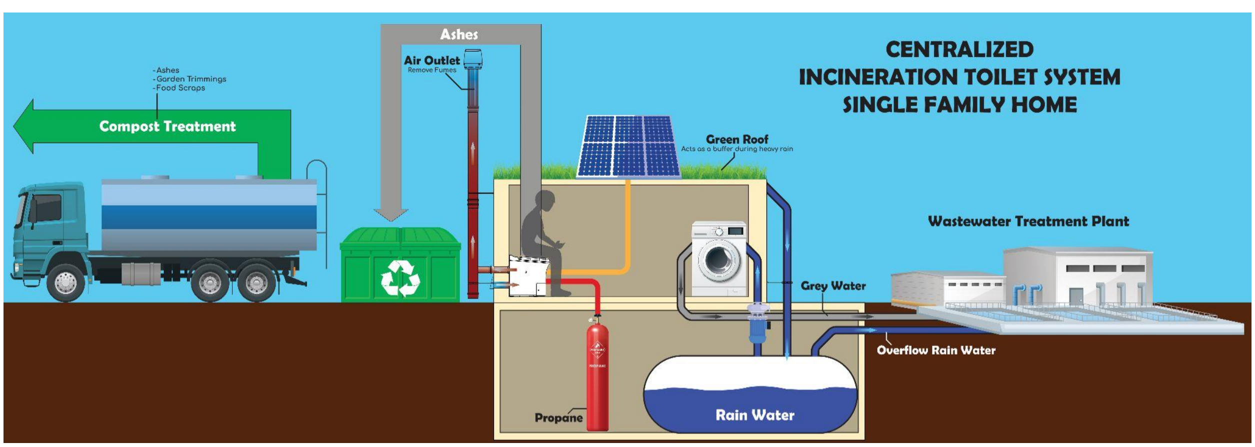


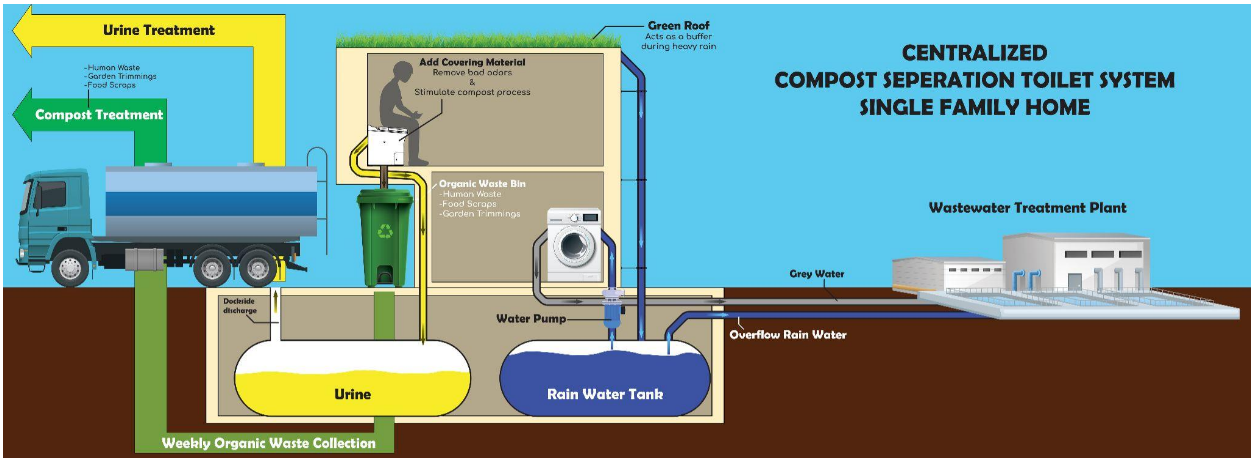




Single Family Home



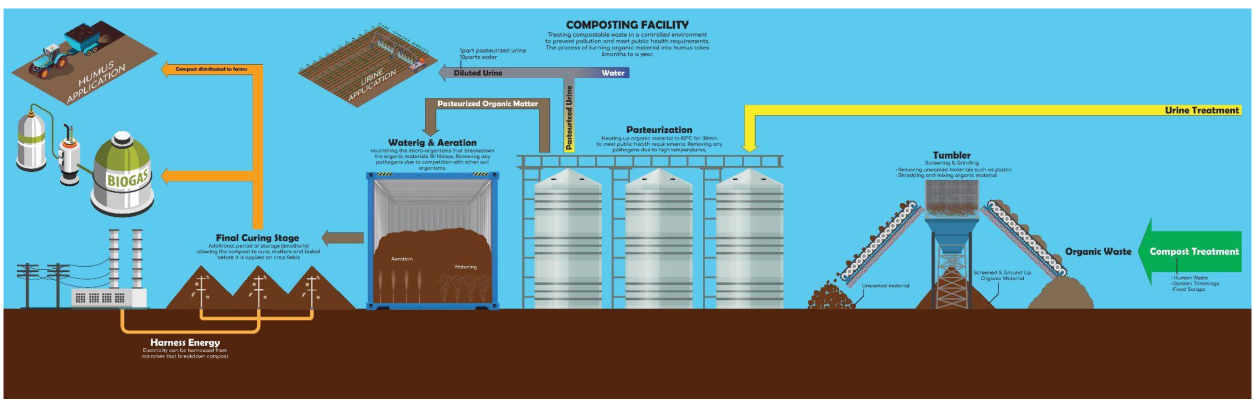




Waste Treatment

Municipal Composting Facility

A more complex wastewater treatment plant that treats human waste, urine and gray water separately can provide unique treatment for each separate resource. The composting process is explained in greater detail in the illustration. Composting facilities can also be an engine for job growth.



Compost Collection

Food scraps, yard trimmings, soiled paper and other organic waste are collected from your green bin weekly, loaded onto a truck, and brought to the composting facility to be processed. The organic material is brought to a composting facility to be turned into compost.

Tumbler

The things that are not supposed to be in the compost are removed right away. Removing unwanted materials such as plastic and metal.

Shredding

The shredder uses large blades to chop up the organic waste into smaller pieces and mixes everything together (City of Hamilton, 2017).

Pasteurization

After the organic waste is ground up and screened for plastic and other bits of trash it is pasteurized at 80 °C for min. 0.5 hours to achieve a satisfactory hygienic quality. During pasteurization, pathogenic bacteria are killed (FREVAR KF, 2023).

Aeration and Watering

The pasteurized organic matter gets evenly distributed into a tunnel where the organic matter is watered and aerated to help nourish the microorganisms that are breaking down the organic matter (City of Hamilton, 2017). The moisture content and oxygen levels in the organic matter are monitored for 10 to 14 days to create perfect conditions for the microorganisms (City of Hamilton, 2017). The composting process removes any pathogenic bacteria due to competition with other soil organisms and high temperatures (50-80 °C). The compost piles are also aerated to reduce greenhouse gas emissions (CNBC, 2018). The piping system filters out dangerous greenhouse gasses produced by microbes. Only treated air is released through the exhaust pipe and into the environment to maximize odor control.

Curing Stage

The organic matter is piled up, left to sit and is cured for 6 months to a year to allow the compost to mature. The finished compost is tested by scientists before it is distributed (City of Hamilton, 2017).

Harness Energy

We can also use the compost process to harness energy from it. Microbial fuel cells are devices that harness energy from the naturally occurring cycles that take place in soils. The microbes that live in soil and sediments eat the organic matter in the soil and to generate energy from that they have to move electrons of the soil through their biochemical pathways and stick those electrons onto something. With those electrons you can power lights (The Coinweaver, 2013).

Compost Distribution

Compost is sold to local farmers who use it to grow cover crops that hold carbon out of the atmosphere and return carbon back to the soil. This is one of the things we can do to slow down climate change (Stories, 2016).

Compost and the Environment

Composting keeps materials out of landfills, it returns nutrients to farms, it reduces the production of potent greenhouse gasses, and it attracts and retains rainwater (Stories, 2016).

Household On-site Waste Treatment

Pretreatment

Lactic acid fermentation (LAF) provides a chemical disinfection which only takes a few hours to weeks and the main effects of the treatments are disinfection and reduction of odors. LAF is easy to manage and reduces fecal pathogens quickly, while the organic matter and nutrients are retained (Evgenieva Kelova, 2022). However, LAF alone does not sufficiently stabilize and sanitize fecal matter, and further treatment is needed before application as soil conditioner or fertilizer (Evgenieva Kelova, 2022).

Maintreatment

Higher microbial activity and temperature in the compost results in more efficient removal of most of the pharmaceutical compounds (Evgenieva Kelova, 2022). However, average treatment time spans over months, requires space, specific design, and knowledge (Evgenieva Kelova, 2022). Composting is limited at low ambient temperature and lactic acid fermentation and/or vermicomposting could be additions, particularly when composting is not successful (Evgenieva Kelova, 2022).

Post Treatment

Vermicomposting transforms and stabilizes the treatment products that were not actively composted at low temperatures (7-20˚C) (Evgenieva Kelova, 2022). The additional treatment step of vermicomposting results in further stabilization and conditioning of the fecal matter. Breaking down the nutrients to plant usable form (Evgenieva Kelova, 2022).

Conclusion & Recommendations

Although ecological sanitation has the real potential to reduce water consumption, electricity use, dependency on finite fertilizer and combat soil degradation they won't be integrated in large numbers any time soon as long as there is no major change in societal norms, political support, economic incentive, resource scarcity, or an environmental or safety concern.
Ecological sanitation toilets will continue to be used in rural areas with no access to water or in underdeveloped countries where people's lives are saved by introducing decentralized ecological sanitation solutions.
However the middle and upper class in developed countries are hesitant to change their habits as they are attached to the comfort and convenience of the flush toilet. They will continue to use the more comfortable flush toilet, for as long as there are no pressing circumstances that demand them to use a different sanitation system.

Although the flush toilet is convenient to use, it is very resource intensive to run and to clean the effluent water because nutrients and biosolids are diluted in the water, which makes it hard to retrieve the nutrients for recycling and reuse. Flush toilets are one of the highest water consuming household products therefore it is a good candidate to replace to decrease your water consumption, electricity use, costs and environmental impact.

To replace the flush toilet three ecological toilets have been selected for this study. From the three toilet systems in this academic study the incinerating toilet is the system that is best suited for both low density rural areas and high density urban areas. Because it is a user friendly system, it requires no handling of waste and the ashes can be handled like any other organic compost matter. Unlike the other toilet systems it doesn't require a lot of space, only a power source. Although safely removing medication residue and pathogens the incineration process does decrease the nutrient level in the ash. That's why the diverting compost toilet came in a close second place as it does produce a safe high nutrient end-product; the only downside is the space and know-how needed to successfully get the desired result out of the composting process. This makes the diverting compost toilet less suitable to integrate in high density urban areas. The vacuum toilet is a complex system that makes obnoxiously loud noise when flushed, it has a lot of moving parts, it requires a septic tank and relies on electricity to run. This makes the vacuum toilet the least desirable of the three.

Needless to say ecological sanitation requires wastewater plants to adapt as the waste doesn't contain any water. Therefore a composting treatment plant is needed that sifts, pasteurized and cures the organic waste. In case dry toilet systems would be implemented in large numbers in urban areas, it is the composting treatment facility that avoids the accumulation of waste and spreading of diseases, by collecting it at a central collection point and treating it for safe reuse on crop fields.

Ecological sanitation and the reuse of nutrients in human waste in agriculture has the potential to make countries more resilient when facing unforeseen circumstances such as supply chain issues and fluctuating prices as a consequence of the pandemic or Russian invasion. Thus making a nation less dependable on imported goods from other countries, decreasing political pressures and increasing its self reliance.

Any sustainable solution that might be introduced in the future relies on a change in culture, a change in societal norms and user acceptance of the sanitation system. A holistic approach is important when implementing a sanitation system, to make sure that no unexpected problems come up during installation and implementation of the system. To get the compliance of a community towards ecological sanitation: needs, wants, habits, religious norms, inherent and learned feelings towards human excreta, expectations and beliefs of the community need to be clear. These various perspectives serve to deliver a holistic image of a society's attitudes and beliefs towards ecological sanitation and reuse of human excreta.

Research so far aimed at limiting the nutrient and pollution load of the effluent, but research and policy attention is shifting from pollutant removal (end of pipe solution) to resource-oriented management (preventive solution at the source) (Evgenieva Kelova, 2022).
The Household level treatment options for dry sanitation systems are limited and there is insufficient understanding about how effective they are in a real-life context.
Better understanding how environmental conditions affect treatment, what can limit the effectiveness, and how that is reflected in the product and its fertilizer value is a step towards building the confidence of institutions, sanitation and agriculture practitioners, and users in the excreta-derived products (Evgenieva Kelova, 2022).
Although the end product might be desirable, the treatment and application should be regulated with best management practices to guide the on-site composting of human waste and the safe use of the resulting compost. Also the process of treating the waste should be facilitated in order to monitor and treat the waste even if the treatment conditions and environmental conditions vary over time.

To envision human excreta as a resource is a way to off-set some of the fertilizer needs and reduce the pressure of nutrient pollution to freshwater and marine environments (Evgenieva Kelova, 2022).

References

Interviews

- Margel. (2023, March 15). Interview Trude Brinck-Johnsen Margel Chief Communications Officer at Cinderella Eco Group AS. *Interview*.
- Solberg. (2023, May 3). *Interview Cristell Solberg Operations Manager Water and Wastewater at FREVAR KF*. Interview.
- Jacobsen. (2023, March 7). *Interview Rolf Jacobsen User of Compost Toilet & Klaro Wastewater Treatment System*. Interview.

Academic Articles

- Kaur Bhatti. (2021, May). *An Explorative Study on Norwegian Users' Understandings and Practices of Vacuum Toilet Systems in Private and Semi-Private Residences*. University of Oslo.
- Kaczala. (2006, August). A Review of Dry Toilet Systems. *University of Kalmar – Department of Technology*.
- Evgenieva Kelova. (2022). *On-site treatment options for recovery of nutrients in dry toilets*.
- PetterD. Jenssen, PetterH. Heyerdahl, Jon Fredrik Hanssen, & Mariya E. Kelova. (2023). *Solar powered dry toilet for cold climate. Results from a pilot study*.
- Oarga-Mulec, Turk, Gerbec, D. Jenssen, Malovrh Rebec, & Valant. (2023). Life cycle assessment of black and greywater treatment 1 solutions for remote and sensitive areas. *MDPI*. https://doi.org/10.3390/xxxxx

Online Articles

- European Commission. (2022, October 26). *Questions and Answers on the new EU rules on treating urban wastewater*. Retrieved April 6, 2023, from https://ec.europa.eu/commission/presscorner/home/en
- European Commission. (2022, October 26). *Urban wastewater*. Environment. Retrieved January 20, 2023, from https://environment.ec.europa.eu/topics/water/urban-wastewater_en
- Norwegian Government. (2021). *Voluntary National Review 2021 Norway*. Ministry of Local Government and Regional Development. Retrieved May 18, 2023, from https://www.regjeringen.no/en/dokumenter/voluntary-national-review-2021-norway/id2863155/

- Ahmad. (2022, November 6). *Negative Effects of Agriculture on the Environment*. CropForLife. Retrieved February 2, 2023, from https://cropforlife.com/negative-effects-of-agriculture-on-the-environment/
- Thames Water. (2023). *The sewage treatment process*. Retrieved February 18, 2023, from https://www.thameswater.co.uk/about-us/responsibility/education/the-sewage-treatment-process
- It Wisely. (2018, December 4). *Journey Through the Pipes - What Happens to Wastewater?* Water Use It Wisely. Retrieved February 18, 2023, from https://wateruseitwisely.com/blog/journey-pipes-happens-wastewater/
- (2018, November 27). *Hoe wordt drinkwater gemaakt?* Ons Water in Nederland. Retrieved February 19, 2023, from https://www.onswater.nl/onderwerpen/hoe-wordt-drinkwater-gemaakt
- Statistics Norway. (2022, June 20). *Municipal water supply*. Retrieved March 1, 2023, from https://www.ssb.no/en/natur-og-miljo/vann-og-avlop/statistikk/kommunal-vannforsyning
- Norks Vann. (2018, June). *The Water Services in Norway*. Norsk Vann. Retrieved March 1, 2023, from https://norskvann.no/wp-content/uploads/The_water_services_in_Norway_2018.pdf
- Reichborn. (2013, June). Maintaining Sustainable Water Services. *Norwegian University of Science and Technology*, page 9. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/232569/649614_FULLTEXT01.pdf?sequence=2&isAllowed=y
- Borgan, E. (2019, October 23). *Wasting water in Norway has consequences for the environment*. Science Norway. Retrieved March 1, 2023, from https://sciencenorway.no/biology-chemistry-climate/wasting-water-in-norway-has-consequences-for-the-environment/1578207
- Kennisportaal Klimaatadaptatie. (2020). *Uitzakken grondwaterstand*. Retrieved March 1, 2023, from https://klimaatadaptatienederland.nl/stresstest/bijsluiter/droogte/basisinformatie/uitzakken-grondwaterstand/
- Water Science School. (2018, June 6). *Groundwater Decline and Depletion*. U.S. Geological Survey. Retrieved March 1, 2023, from https://www.usgs.gov/special-topics/water-science-school/science/groundwater-decline-and-depletion#:~:text=The%20volume%20of%20groundwater%20in,caused%20by%20sustained%20groundwater%20pumping.
- *Frank Deboosere: "De 'waterafdruk' van élke Vlaming is maar liefst 7400 liter per dag!"* (2023, January 8). Radio2. Retrieved March 2, 2023, from https://radio2.be/lees/frank-deboosere-de-waterafdruk-van-elke-vlaming-is-maar-liefst-7400-liter-per-dag
- Dagestad, & Venvik. (2021, July 30). *Groundwater Use*. Norges Geologiske Undersøkelse. Retrieved March 2, 2023, from https://www.ngu.no/en/topic/groundwater-use

- RioNed. (2023). *Grondwater*. Retrieved March 2, 2023, from https://www.riool.info/grondwater
- Huyghebaert. (2023, January 6). *Grondwaterpeil laag tot erg laag voor tijd van het jaar, ondanks regen van voorbije weken*. Vrtnws. Retrieved March 2, 2023, from https://www.vrt.be/vrtnws/nl/2023/01/06/grondwaterstand/
- Oslo kommune. (2023). *Water and waterways*. Oslo Kommune. Retrieved March 2, 2023, from https://www.oslo.kommune.no/politics-and-administration/statistics/environment-status/water-and-waterways/
- Eurostat. (2020, November 18). *Do you have access to your own indoor flushing toilet?* Retrieved March 2, 2023, from https://ec.europa.eu/eurostat/web/products-eurostat-news/-/EDN-20201118-1
- Norway's News in English. (2018, July 23). *Groundwater level sinks to record low*. Retrieved March 2, 2023, from https://www.newsinenglish.no/2018/07/23/groundwater-level-sinks-to-record-low/
- Steinberg. (2017, June 27). *Drinking water in Norway*. Norwegian Institute of Public Health. Retrieved March 2, 2023, from https://www.fhi.no/en/op/hin/infectious-diseases/drinking-water-in-Norway/
- United Nations. (2022, November 19). *Groundwater and sanitation – making the invisible visible*. Retrieved March 2, 2023, from https://www.un.org/en/observances/toilet-day
- O'Donnell. (2021, May 31). *Groundwater vs. Surface Water - What's the Difference?* Sensorex. Retrieved March 2, 2023, from https://sensorex.com/2021/05/31/groundwater-vs-surface-water/
- Lyså. (2015, February 25). *Quaternary Geology*. Geology Survey of Norway. Retrieved March 2, 2023, from https://www.ngu.no/en/topic/quaternary-geology
- Winfield. (2022, August 10). *Norway Tap Water Quality Report: Is it Drinkable?* Water Defense. Retrieved March 2, 2023, from https://waterdefense.org/water/tap/norway/
- NVE. (2022, December 7). *Groundwater*. Retrieved March 2, 2023, from https://www.nve.no/vann-og-vassdrag/vannets-kretsloep/vannet-under-bakken-markvann-og-grunnvann/grunnvann/
- United Nations. (2023). *Norway - Progress on Achieving SDG6*. Retrieved March 2, 2023, from https://sdgs.un.org/basic-page/norway-34136#:~:text=Almost%20100%20%25%20of%20the%20Norwegian,connected%20to%20municipal%20wastewater%20systems.
- Ritchie, & Roser. (2018, July). *Water Use and Stress*. Our World in Data. Retrieved March 2, 2023, from https://ourworldindata.org/water-use-stress
- Ritchie, & Roser. (2021, June). *Clean Water*. Our World in Data. Retrieved March 2, 2023, from https://ourworldindata.org/water-access
- Ritchie, & Roser. (2021, June). *Sanitation*. Our World in Data. Retrieved March 2, 2023, from https://ourworldindata.org/sanitation
- World Health Organization. (2022, March 21). *Sanitation*. Retrieved March 5, 2023, from https://www.who.int/news-room/fact-sheets/detail/sanitation
- Statistics Norway. (2022, November 18). *Municipal wastewater*. Retrieved March 5, 2023, from

https://www.ssb.no/en/natur-og-miljo/vann-og-avlop/statistikk/utslipp-og-rensing-av-kommunalt-avlop
- Statistics Norway. (2017, December 19). *Wastewater statistics 'mapped out.'* Retrieved March 5, 2023, from https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/wastewater-statistics-mapped-out
- Environment Norway. (2022, December 22). *Freshwater*. Retrieved March 5, 2023, from https://www.environment.no/topics/freshwater/
- Cunitz. (2018, June 25). *Water: a Finite Resource*. Earthecho Water Challenge. Retrieved March 5, 2023, from https://www.monitorwater.org/post/water-a-finite-resource#:~:text=Despite%20the%20huge%20area%20the,prove%20detrimental%20in%20the%20future.
- SuSanA Secretariat. (2008, September 25). *Worldwide - Posters about ecosan*. Flickr. https://www.flickr.com/photos/gtzecosan/albums/72157607499118612/with/2888422363/
- Wikipedia. (2015, July 13). *Ecological sanitation*. Retrieved March 7, 2023, from https://en.wikipedia.org/wiki/Ecological_sanitation
- Rotary of Peru SAC. (2023). *Beginning*. Rotaria Del Peru. Retrieved March 7, 2023, from https://www.rotaria.net/peru3/rotaria/
- Cydzik-Kwiatkowska, Milojevic, & Jachimowicz. (2021, October). *Agricultural Use of Sewage Sludge as a Threat of Microplastic (MP) Spread in the Environment and the Role of Governance*. Research Gate. Retrieved March 7, 2023, from https://www.researchgate.net/publication/355056879_Agricultural_Use_of_Sewage_Sludge_as_a_Threat_of_Microplastic_MP_Spread_in_the_Environment_and_the_Role_of_Governance
- WooWoo Waterless Toilets. (2023). *How to deal with urine from a compost toilet*. Retrieved March 16, 2023, from https://www.waterlesstoilets.co.uk/dealing-with-urine/
- Meadows . (2019, November 27). *Sustainable Systems*. YouTube. Retrieved April 2, 2023, from https://www.youtube.com/watch?v=vJ1STks8MUU
- Farm Progress. (2017, April 3). *How long does it take to build organic matter?* Retrieved April 2, 2023, from https://www.farmprogress.com/management/how-long-does-it-take-to-build-organic-matter-
- Rodale Institute. (2023). *What is crop rotation?* Retrieved April 2, 2023, from https://rodaleinstitute.org/why-organic/organic-farming-practices/crop-rotations/
- Kaczala. (2006, January). *A Review of Dry Toilet Systems*.
- *"Dirt" - A New Documentary About Saving Our Soil*. (2022, September 2). YouTube. Retrieved April 5, 2023, from https://www.youtube.com/watch?v=A8mawEmm49o&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMle&index=17
- The Coinweaver. (2013, March 10). *Dirt! The Movie*. YouTube. Retrieved April 5, 2023, from https://www.youtube.com/watch?v=HfRvuPIN4kk&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMle&index=18

- Lauwerier. (2023, January 30). *Antidepressiva en angstremmers maken vissen roekeloos: "Spoel geen medicijnen door."* Vrtnws. Retrieved April 6, 2023, from https://www.vrt.be/vrtnws/nl/2023/01/30/vissen-raken-in-de-war-door-antidepressiva-en-angstremmers-in-wa/
- Miljødirektoratet. (2022, March 22). *Maintains need for nitrogen cuts in the Oslofjord*. Retrieved April 6, 2023, from https://www.miljodirektoratet.no/aktuelt/fagmeldinger/2022/mars-2022/nitrogen-ytre-oslofjord/
- FREVAR KF. (2023). *Wastewater treatment plants*. Retrieved April 6, 2023, from https://frevar.no/avlopsanlegg/
- Statistics Norway. (2018, December 18). *Municipal wastewater 2017*. Retrieved April 7, 2023, from https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/municipal-wastewater-2017
- The Norwegian Environment Agency. (2016). *Screening programme 2015*. Retrieved April 7, 2023, from https://www.miljodirektoratet.no/globalassets/publikasjoner/m597/m597.pdf
- Lina Nikoleris. (2016, March 4). *Estrogen in birth control pills has a negative impact on fish*. Science Daily. Retrieved April 7, 2023, from https://www.sciencedaily.com/releases/2016/03/160304092230.htm
- Lubofsky. (2016, October 28). *The promise of perennials: Working through the challenges of perennial grain crop development*. CSA News. Retrieved April 19, 2023, from https://acsess.onlinelibrary.wiley.com/doi/10.2134/csa2016-61-11-1
- Saner. (2019, December 9). *The no-flush movement: the unexpected rise of the composting toilet*. The Guardian. Retrieved May 1, 2023, from http://www.theguardian.com/global/2019/dec/09/no-flush-movement-composting-toilet-clean-water-waste-fertiliser-eco-revolution
- coway. (n.d.). *A Brief History of Toilets: Waste Disposal Through the Ages*. Cowaymega. Retrieved May 2, 2023, from https://cowaymega.com/blogs/blog/a-brief-history-of-toilets-waste-disposal-through-the-ages
- OHCHR. (2022). *OHCHR and the rights to water and sanitation*. United Nations. Retrieved May 2, 2023, from https://www.ohchr.org/en/water-and-sanitation#:~:text=Globally%2C%202.1%20billion%20people%20lack,people%20lack%20safely%20managed%20sanitation.
- World Health Organization. (2019, June 18). *1 in 3 people globally do not have access to safe drinking water – UNICEF, WHO*. Retrieved May 2, 2023, from https://www.who.int/news/item/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who
- de los Reyes. (2021, June 15). *A brief history of toilets*. Ted-ed. Retrieved May 2, 2023, from https://www.youtube.com/watch?v=0dYk99S98Jc&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=26

- Dickin, Bayoumi, Giné, Andersson, & Jiménez. (2020, May 25). *Sustainable sanitation and gaps in global climate policy and financing*. NPJ Clean Water. https://doi.org/10.1038/s41545-020-0072-8
- Kildwick. (2019, July 21). *History of the dry toilet*. Retrieved May 2, 2023, from https://www.kildwick.com/en/discover/good-to-know/the-history-of-dry-composting-toilets
- Weird History. (2020, January 12). *The History of Toilets*. Retrieved May 2, 2023, from https://www.youtube.com/watch?v=TaSrf2DNy5w&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=28
- Wikipedia. (2016, May 22). *Dry Toilet*. Retrieved May 2, 2023, from https://en.wikipedia.org/wiki/Dry_toilet
- Lewis-Hammond. (2014, July 23). *Composting toilets: a growing movement in green disposal*. The Guardian. Retrieved May 2, 2023, from http://www.theguardian.com/lifeandstyle/2014/jul/23/composting-toilets-a-growing-movement-in-green-disposal
- Sheehan. (2022, October 11). *6 Clever Uses for Urine in the Garden*. Rural Sprout. Retrieved May 4, 2023, from https://www.ruralsprout.com/urine-in-the-garden/
- Rich Earth Institute. (2023). *Fertilizer from Urine How It Works*. Retrieved May 4, 2023, from https://richearthinstitute.org/how-it-works/
- Findlay. (2021). *The Living Machine*. Global Ecovillage Network. Retrieved May 5, 2023, from https://ecovillage.org/solution/the-living-machine/
- Start. (2019, October 5). *From raw sewage to fresh water*. DW. Retrieved May 5, 2023, from https://www.dw.com/en/turning-raw-sewage-into-fresh-water-the-organic-way/a-48194502
- Oarga-Mulec, Turk, Gerbec, D. Jenssen, Malovrh Rebec, & Valant. (2023). Life cycle assessment of black and greywater treatment 1 solutions for remote and sensitive areas. *MDPI*. https://doi.org/10.3390/xxxxx
- Kaczala. (2006, August). A Review of Dry Toilet Systems. *University of Kalmar – Department of Technology*.
- EUR-Lex. (2023). *Primacy of EU law*. Retrieved May 8, 2023, from https://eur-lex.europa.eu/EN/legal-content/glossary/primacy-of-eu-law-precedence-supremacy.html#:~:text=The%20principle%20of%20the%20primacy,)%2C%20EU%20law%20will%20prevail.
- B Peterson. (2023, March 16). *Dutch Farmers: Canaries in the Globalist Coal Mine | Michael Yon & Eva Vlaardingerbroek | EP 340*. YouTube. Retrieved May 8, 2023, from https://www.youtube.com/watch?v=pqHQN54XCL0&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=23
- Stories. (2016, June 30). *How San Francisco Is Becoming A Zero Waste City*. YouTube. Retrieved May 9, 2023, from https://www.youtube.com/watch?v=Cg3OA1s8-SI&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=30
- City of Hamilton. (2017, August 31). *Tour Hamilton's Central Composting Facility*. YouTube. Retrieved May 9, 2023, from

https://www.youtube.com/watch?v=MSJ8mkbl75Q&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=34
- CNBC. (2018, July 17). *How San Francisco Became A Global Leader In Waste Management*. YouTube. Retrieved May 9, 2023, from https://www.youtube.com/watch?v=vDMgMvcCm6w&list=PLdSZIa7nY5GgCpxQuI4qrfSi1dN7SqMIe&index=29
- Stockholm University. (2023, May 17). *The nine planetary boundaries*. Stockholm Resilience Centre. Retrieved May 17, 2023, from https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html
- Oslo Municipality. (2022, July 28). *Still low water reservoirs*. Retrieved May 19, 2023, from https://www.oslo.kommune.no/politikk/byradet/for-pressen/pressemeldinger-fra-byradet/fortsatt-lave-vannmagasiner
- Zeldovich, L. (2019, November 18). *A History of Human Waste as Fertilizer*. JSTOR Daily. Retrieved May 20, 2023, from https://daily.jstor.org/a-history-of-human-waste-as-fertilizer/