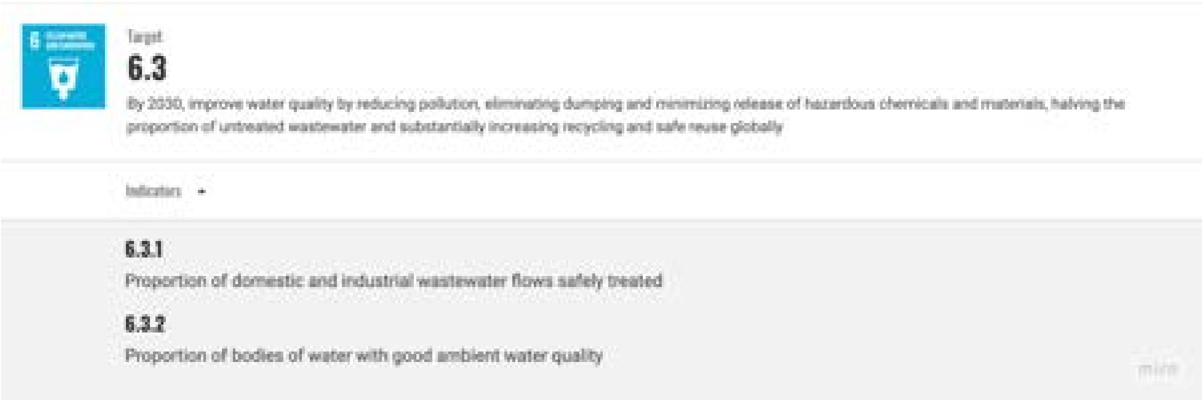
Decentralizing wastewater treatment and energy generation

Team 6 - AquaIntelligence

Adrià CASANOVA
Davide ANDRESANI
Guanda ZHOU
Mathilde MELLONI
Rana AZZI

Introduction

Sustainable Development Goals



The United Nations Sustainable Development Goals (SDGs) are a global framework established to address a wide range of social, economic, and environmental challenges by 2030. These 17 goals aim to create a better and more sustainable future for all, tackling issues such as poverty, inequality, climate change, and environmental degradation.

SDG 6: Clean Water and Sanitation is pivotal to this mission, focusing on ensuring the availability and sustainable management of water and sanitation for all. Within this goal, Target 6.3 specifically aims to improve water quality by reducing pollution, minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally by 2030.

Achieving SDG 6.3 involves:

- Enhancing Wastewater Treatment: Increasing the treatment of wastewater to prevent pollution of water bodies.
- Reducing Contaminants: Cutting down the release of harmful substances into water systems.
- Promoting Recycling and Reuse: Encouraging the safe reuse of water to conserve resources.

SDG 6.3 underscores the importance of clean water in maintaining health, supporting ecosystems, and fostering sustainable development, emphasizing the need for innovative solutions and concerted efforts to address water pollution and improve wastewater management worldwide.

Understanding the problem

In pursuit of the United Nations' Target 6.3, our project aims to transform wastewater management in Lebanon, addressing critical issues of water quality and energy production. Currently, only 8% of Lebanon's wastewater is treated, primarily due to prohibitive costs and persistent energy shortages, leading to dire environmental and public health consequences. Untreated wastewater frequently flows into rivers, groundwater, and the sea, causing significant pollution and posing serious health risks to the population.

Lebanon's energy crisis is one of the primary obstacles to effective wastewater management. The country faces chronic electricity shortages, with many regions experiencing daily power outages lasting several hours. This lack of reliable electricity means that many wastewater treatment facilities are non-operational or function well below capacity. Consequently, untreated wastewater is discharged directly into natural water bodies, leading to severe contamination.

The water supply situation in Lebanon is equally concerning. Many communities rely on rivers and groundwater sources that are increasingly polluted by untreated wastewater. This contamination raises the cost and complexity of accessing clean water, as additional treatment is required to make it safe for consumption and use. The economic burden of water treatment and healthcare costs associated with waterborne diseases further strains the country's resources.

Moreover, Lebanon's infrastructure for wastewater treatment is outdated and insufficient to meet the needs of its growing population. Investment in modern, energy-efficient treatment facilities is urgently needed. However, the financial and logistical challenges of upgrading and expanding these systems are significant.

In light of these challenges, our project seeks to implement innovative solutions that integrate wastewater treatment with renewable energy production. By leveraging advanced technologies and sustainable practices, we aim to improve water quality, enhance public health, and alleviate the economic burden on Lebanon. Through these efforts, we strive to contribute to the achievement of the United Nations' Target 6.3, ensuring the sustainable management of water and sanitation.

Solution

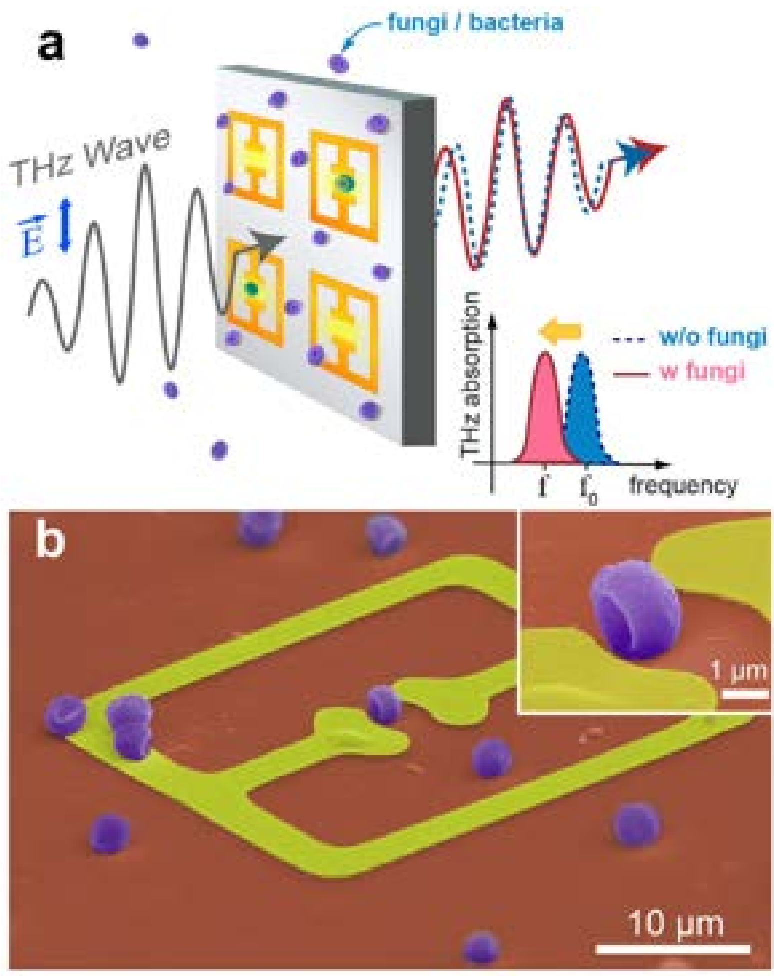
Our solution consists of two pivotal steps designed to harness the potential of wastewater for sustainable energy production and environmental improvement.

Step 1: Data Collection and Analysis

The first step involves deploying advanced sensors within wastewater pipes to monitor and measure the concentration of bacteria, sludge, and other compounds. These sensors provide real-time data on wastewater composition, essential for identifying energy-rich locations.

We will use metamaterials operating in the terahertz (THz) frequency range in our sensors due to their promising potential for fabricating highly sensitive and selective microbial detection devices.

Metamaterials consist of periodically arranged, sub-wavelength metallic elements and exhibit unique electromagnetic properties. In addition, the metamaterials have gap structures characterized by strongly localized and enhanced fields, enabling sensitive detection of extremely small amounts of chemical and biological substances. In particular, metamaterials operating in the THz frequency range have a micro-sized gap and can therefore serve as an ideal platform for the sensitive detection of fungi and bacteria, because the size of these microorganisms is compatible with the gap size. Moreover, THz metamaterials are extremely sensitive to the substances near the surface, which is favorable for sensing in an aqueous environment.



The collected data is transmitted to a data center powered by ULTRARAM technology, where it is thoroughly analyzed to pinpoint areas with the highest potential for energy production. By examining the concentrations of energy-producing components, we can identify the optimal locations for establishing energy-positive wastewater treatment plants. The analysis results in a detailed mapping of these locations, which we then suggest for the installation of efficient wastewater treatment facilities.

Step 2: Implementation and Energy Production

The second step involves communicating our findings to local municipalities, recommending the installation of energy-positive wastewater treatment plants in the identified areas.
Energy production is achieved through the anaerobic digestion of organic compounds in wastewater.

Step 2.1: ***Anaerobic digestion***

Anaerobic digestion is a process used to extract energy from wastewater by breaking down organic matter in an oxygen-free environment. This involves various microorganisms that decompose complex organic compounds into simpler molecules, producing biogas as the main by-product.

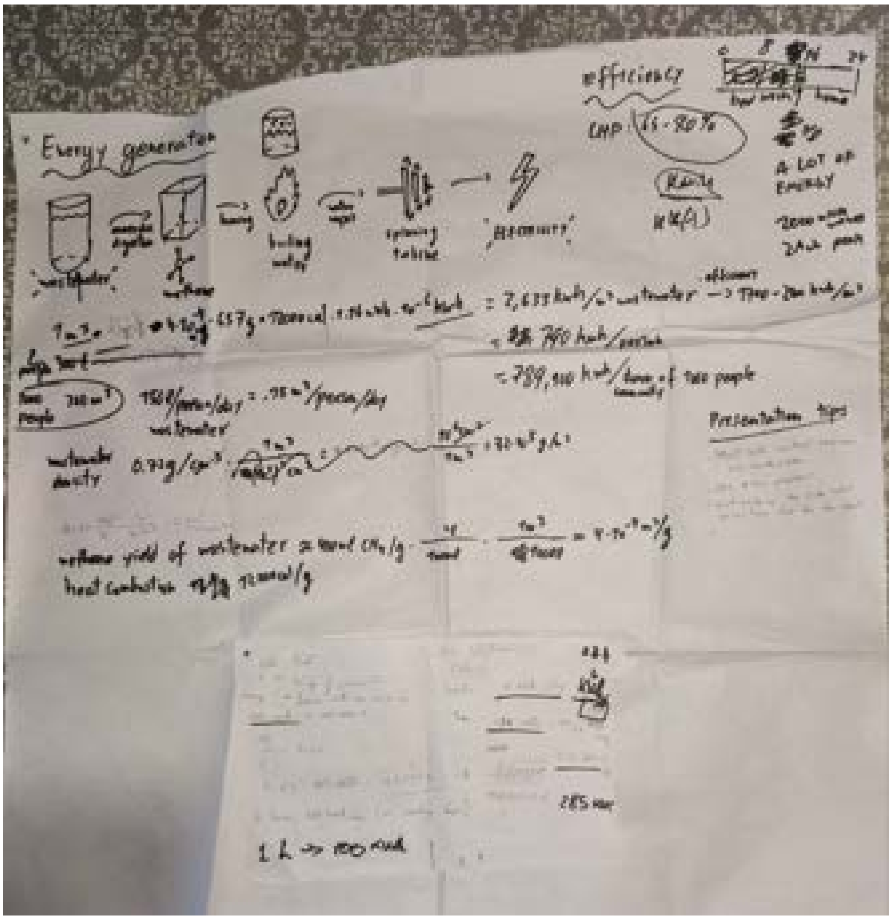
Anaerobic digestion can be enhanced by preparing the wastewater through thermal hydrolysis. This process consists in three steps:

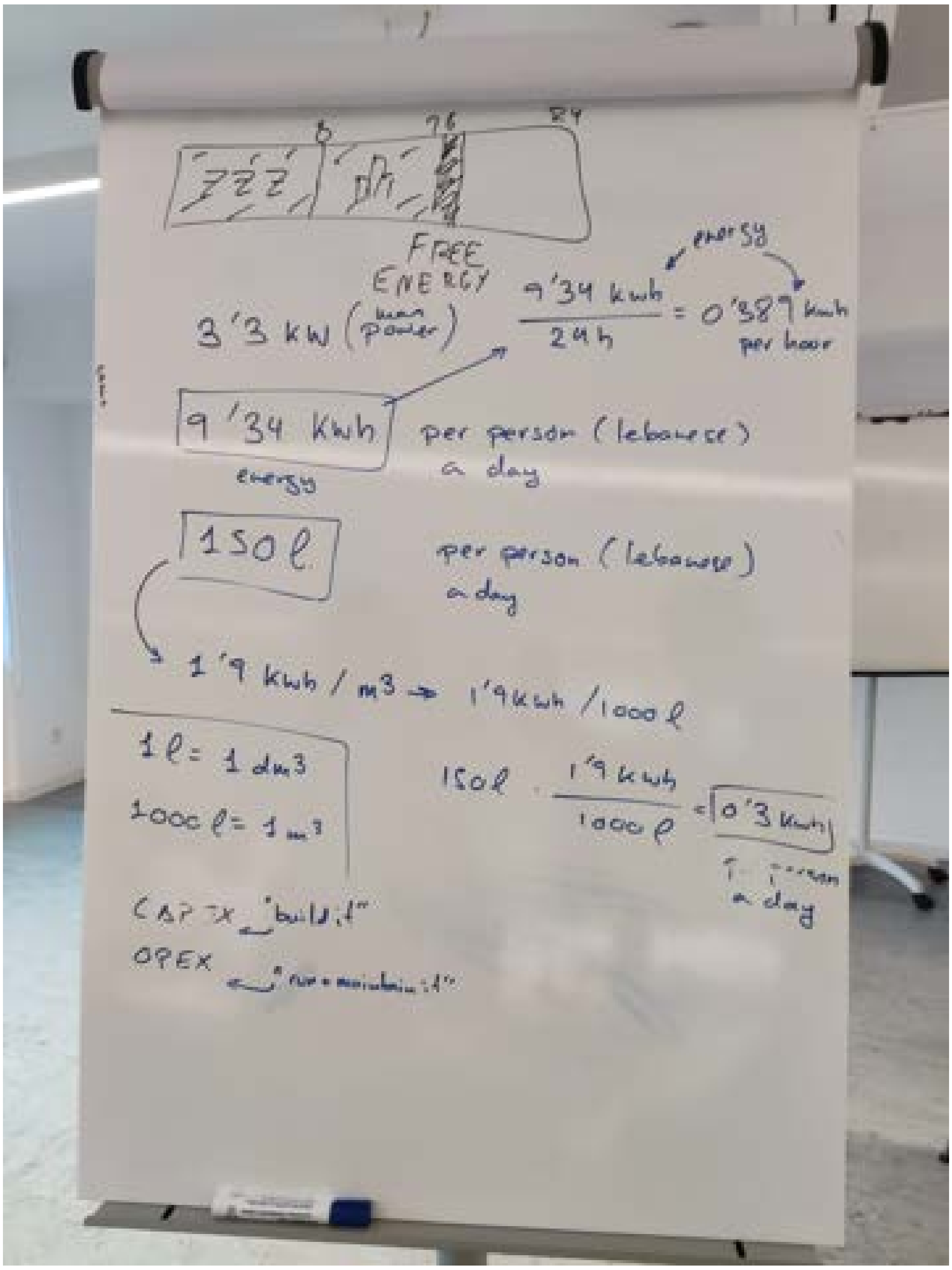
1. Sludge is heated to 150-180°C around 6-12 bar pressure, breaking down complex organic molecules.
2. Under these conditions, the sludge undergoes hydrolysis, where large organic molecules such as proteins, fats, and carbohydrates are broken down into simpler, smaller molecules
3. The mixture is cooled and depressurized, further disrupting cell structures.

The generated biogas from anaerobic digestion is then fed into existing combined heat and power (CHP) plants in the area. These plants convert the biogas into heat and electricity, significantly reducing pollutant emissions compared to fossil fuels and producing clean energy.

Our process generates between 1.7 to 2.1 kWh per cubic meter of wastewater, compared to the 0.5 to 2 kWh required for the treatment process. On average, this results in a surplus energy production of 34%, sufficient to guarantee one hour of electricity per day for a Lebanese inhabitant. That is, with the wastewater produced by one individual during a day, we are able to power his/her/their electricity consumption during one hour.

The following picture shows the calculation of the provided data. The ground values we consider, like the volume of methane produced per gram of wastewater are extracted from the references present at the end of this report.


Energy generation
boiling water
spinning turbine
electricity
efficiency
A LOT OF ENERGY
Presentation tips



Utilizing our rich dataset, we also train an AI system to predict microorganism flows in wastewater, enabling real-time adaptation and optimization of energy generation for municipalities.

Sustainable Cycle and Benefits

The energy produced from wastewater powers the treatment process, creating a self-sustained cycle that continuously produces clean water for various uses, including agriculture and industrial applications. By transforming wastewater into a valuable energy resource, we not only improve water quality but also provide a sustainable solution to Lebanon's energy crisis. This approach reduces environmental pollution and offers economic relief by lowering the costs associated with accessing clean water.

Existing role model

Danish water utility Aarhus Vand operates an energy-positive wastewater treatment plant. Through advanced anaerobic digestion and combined heat and power (CHP) systems, the water utility not only achieves self-sufficiency but also generates surplus energy. The plant is now producing 50 per cent more electricity than it consumes. Biogas generated in the anaerobic digestion is converted into electricity and heat through a combined heat and power (CHP) plant.

Meanwhile German utility Hamburg Wasser has also made significant strides in energy generation from wastewater. By employing advanced anaerobic digestion technologies and implementing efficient sludge treatment processes, the utility minimizes energy consumption while maximizing energy recovery. This process yields approximately 450,000 kilowatt hours of electricity and 690,000 kilowatt hours of heat annually. Surplus energy is sufficient to meet the energy needs of the entire water cycle.

Context Analysis

Stakeholders

In the realm of wastewater management, various stakeholders play pivotal roles:

Local Municipalities engage closely with the technology, integrating it into existing infrastructure and overseeing day-to-day operations.

Wastewater Treatment Plant Operators serve as end-users, providing critical feedback on design, efficiency, and leveraging energy savings.

Local Communities are the ultimate beneficiaries, enjoying enhanced water quality and free daily energy from the treatment process, requiring active engagement to communicate benefits and encourage investment.

Finally, **Energy Companies** and **Investors** stand as potential key players, drawn by the project's focus on treatment and energy production, with investments holding the power to propel the initiative forward, contingent upon the return on investment.

Trends

Decentralization: There is a growing trend towards decentralizing wastewater treatment to improve efficiency, reduce transportation costs, and enhance resource recovery. Decentralized systems are smaller, more flexible, and can be tailored to local needs.

Decentralized systems can better integrate advanced energy recovery technologies like anaerobic digestion on a smaller scale, making it more adaptable and resilient. This aligns with the push towards sustainable and self-sufficient communities.

AI: the artificial intelligence revolution is also affecting wastewater treatment. Here, predictive algorithms are being used to optimize each step of the water cleaning and to detect emerging contaminants.

Emerging contaminants removal: the proportion of pharmaceuticals, personal care products and microplastics in wastewater is increasing, leading to the development of new technologies to detect and remove them. These include oxidation processes and activated carbon filtration.

Resource recovery technologies: a lot of research is being done to find nutrients and other valuable materials that could be potentially extracted from wastewater. Our project fits in this category by generating electricity through anaerobic digestion.

Technologies

- ☐ **Artificial Intelligence**

  Our project leverages random forests, an AI predictive algorithm, to optimize energy generation from wastewater. Using our devices, we measure the flow of bacteria in wastewater at specific locations over time. This data is then used to train an AI system to predict future bacterial concentrations in these water bodies. The benefits of random forests that we'll leverage are their flexibility and scalability. This will allow us to use all kinds of data from sensors and to improve the model in the future with more data. Moreover, random forests don't overfit and are efficient models.

  By accurately forecasting increases or decreases in bacterial levels, we can adjust the energy generation process in real-time, ensuring maximum efficiency. This predictive capability allows us to fine-tune the energy generators to adapt to incoming bacterial flows, thereby maximizing energy output while minimizing resource usage. In essence, our AI-driven approach ensures the most efficient and sustainable energy production from wastewater.

- ☐ **ULTRARAM**

  Role of ULTRARAM in the Project

  A. **Data Collection and Analysis:**

     We deploy advanced sensors in wastewater pipes to measure the concentration of bacteria, sludge, and other compounds. These sensors generate large volumes of data that need to be processed quickly and efficiently.

  B. **Efficient Data Transfer:**

     The data collected from sensors is transferred to a central data center equipped with ULTRARAM technology. The fast and low-energy switching capabilities of ULTRARAM ensure rapid and efficient data transfer and storage.

  C. **AI Training and Predictive Analytics:**

The high-speed data processing capabilities of ULTRARAM are leveraged to train our AI systems. The AI uses historical data to predict future bacterial concentrations in wastewater, allowing us to optimize energy generation processes.

- [ ] **H-cube and IALL**

We did not use H-cube and IALL technologies because their specific strengths do not align with the precise needs of our wastewater management project. H-cube's broad-area hyperspectral imaging is not suitable for the focused, continuous measurements required for bacterial analysis in wastewater. Similarly, IALL's advanced tunable lenses, while excellent for applications requiring high-quality, adjustable imaging, do not significantly enhance our real-time monitoring and data analysis processes.

Implications

Positive Implications

1. Improved Water Quality:
    - Impact: By increasing the treatment of wastewater, the project will significantly reduce the pollution of rivers, groundwater, and the sea.
    - Benefit: This leads to cleaner water sources, reducing health risks and improving the overall environmental quality.

2. Sustainable Energy Production:
    - - Impact: Utilizing anaerobic digestion to produce biogas from wastewater provides a renewable energy source.
    - - Benefit: This contributes to energy sustainability, reducing reliance on non-renewable energy sources and lowering greenhouse gas emissions.

3. Economic Relief:

- Impact: With cleaner water sources, the cost of accessing and treating water is reduced.
- Benefit: This economic relief can be significant for municipalities and residents, freeing up resources for other essential services.

4. Technological Advancements:
    - Impact: The project's use of advanced sensors, AI, and renewable energy technologies promotes innovation.
    - Benefit: This can spur further technological developments and attract investments in sustainable technologies.

5. Community Health Improvement:
    - Impact: Reducing water pollution decreases the prevalence of waterborne diseases.
    - Benefit: Improved public health outcomes can enhance the quality of life and reduce healthcare costs.

6. Environmental Protection:
    - Impact: Treating wastewater before it is discharged protects ecosystems and biodiversity.
    - Benefit: This ensures the sustainability of local flora and fauna, contributing to a balanced ecosystem.

Negative Implications

1. High Initial Costs:
    - Impact: Implementing advanced wastewater treatment and energy production technologies requires significant upfront investment.
    - Drawback: This may strain financial resources, especially in economically challenged areas, and require substantial funding.

2. Operational Challenges:

- Impact: The need for continuous maintenance and operation of advanced systems can pose logistical challenges.
- Drawback: This may lead to increased operational costs and the need for skilled personnel to manage the systems effectively.

Design Process

Methodology

The design process followed a collaborative and dynamic approach, emphasizing idea generation during class time and leveraging the expertise of coaches to find effective solutions to specific problems. The process began with thorough research on SDG 6.3 and related terms, providing a solid foundation for subsequent activities. During class sessions, we engaged in brainstorming to generate a wide range of ideas. These sessions fostered creativity and open discussion, allowing for diverse perspectives and innovative thinking.
Ideas generated during these sessions were then presented and discussed collectively. Through a voting process, the most promising concepts were identified and selected for further exploration.

Steps

1. Research

Objective

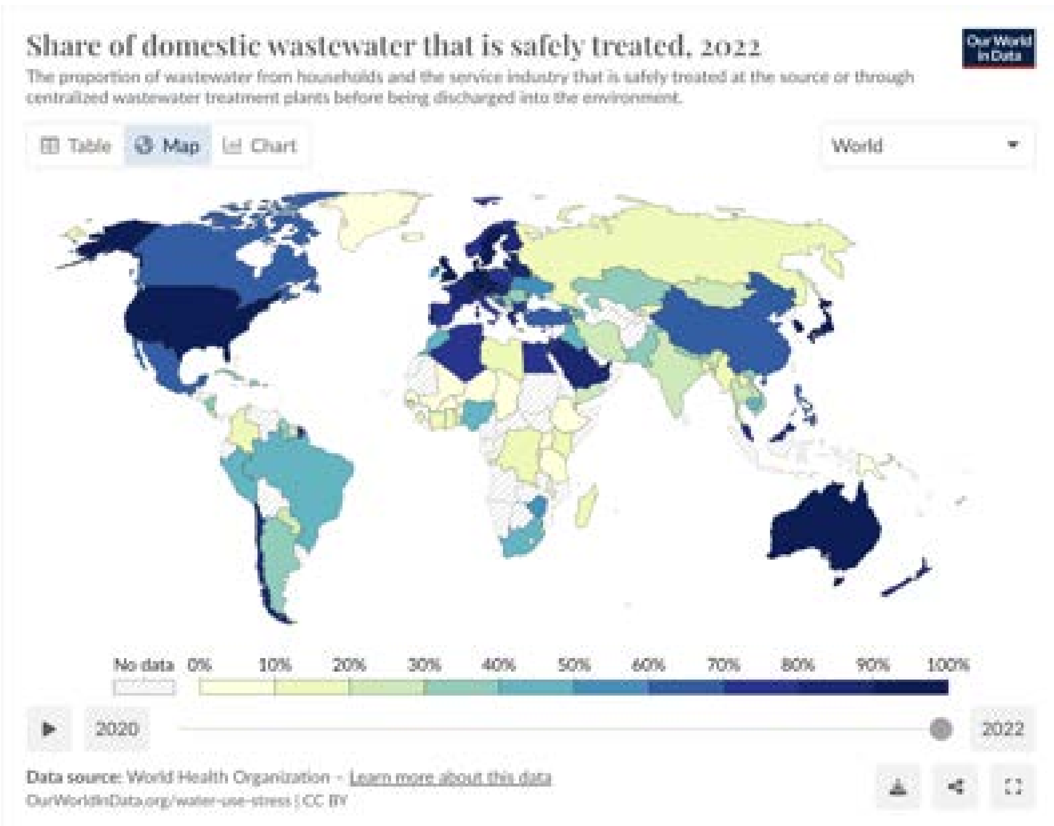
The primary objective of this initial phase was to build a comprehensive understanding of Sustainable Development Goal (SDG) 6.3 and its associated terms. This foundational knowledge was critical for informing subsequent activities and ensuring that the ideas generated were relevant and impactful.

Activities

- Literature Review: Conducted extensive literature reviews on SDG 6.3, which focuses on improving water quality, wastewater treatment, and reducing pollution.
- Case Studies and Current Projects: Analyzed various case studies and ongoing projects related to water management and sustainability.
- Challenges and Opportunities: Identified key challenges and opportunities associated with achieving SDG 6.3 through detailed analysis.

Outcome

This phase resulted in a robust knowledge base that was crucial for the brainstorming sessions that followed. It ensured that all participants had a solid understanding of the topic, enabling us to contribute effectively to the idea generation process.



2. Ideas Brainstorming

Each of us came up with potential ideas and shared them with the group. Here are some initial standout ideas:

- Household Filter Plus Monitor

This idea involves having household wastewater go through initial treatment steps to ease the load on wastewater treatment plants. Additionally, an app would allow households to monitor the components of their wastewater, identifying harmful products to stop using. However, concerns include user privacy and the effectiveness of this solution, as most wastewater originates from agriculture and industries, not households. We integrated part of this idea into our final solution by proposing sensors in the city sewage system instead of household pipes.

- AI Optimization

Several team members suggested using AI to optimize the treatment process, focusing on energy saving, data analysis, and operational efficiency. In our final solution, we incorporated AI, particularly using ultraram technology to save energy while analyzing data. We noted that AI requires large amounts of real-time data and should support, rather than make, decisions.

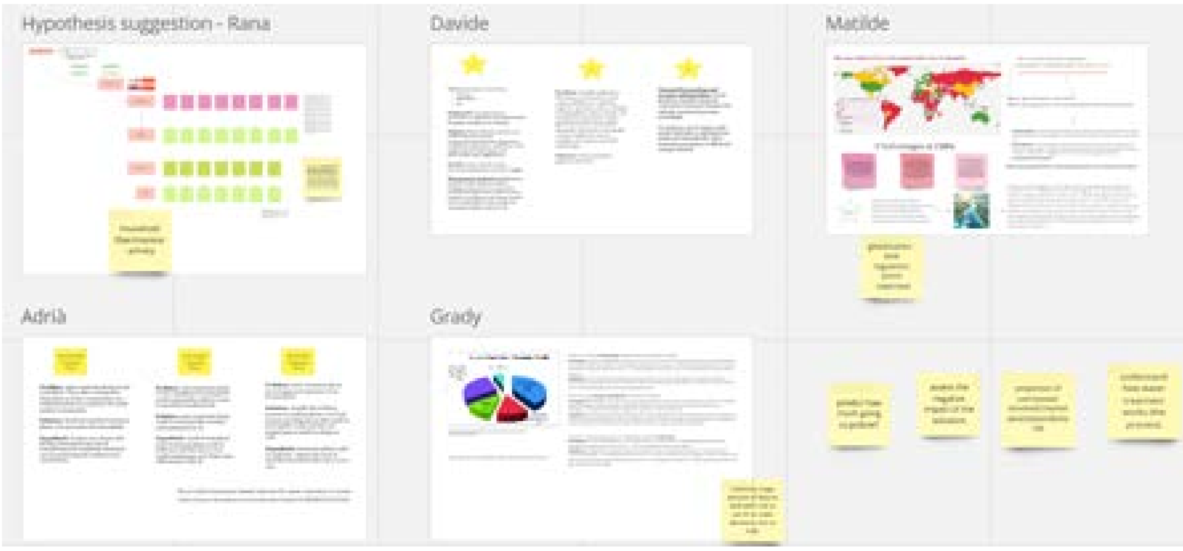
- Drone Surveillance

Another idea was deploying drones equipped with CERN technologies over rivers to detect pollution and report it to relevant organizations. While promising, this idea faced challenges regarding cost, scalability, and regulatory issues across different regions. The concept inspired us to think about widespread sensor deployment for monitoring and reporting.

- Decentralization

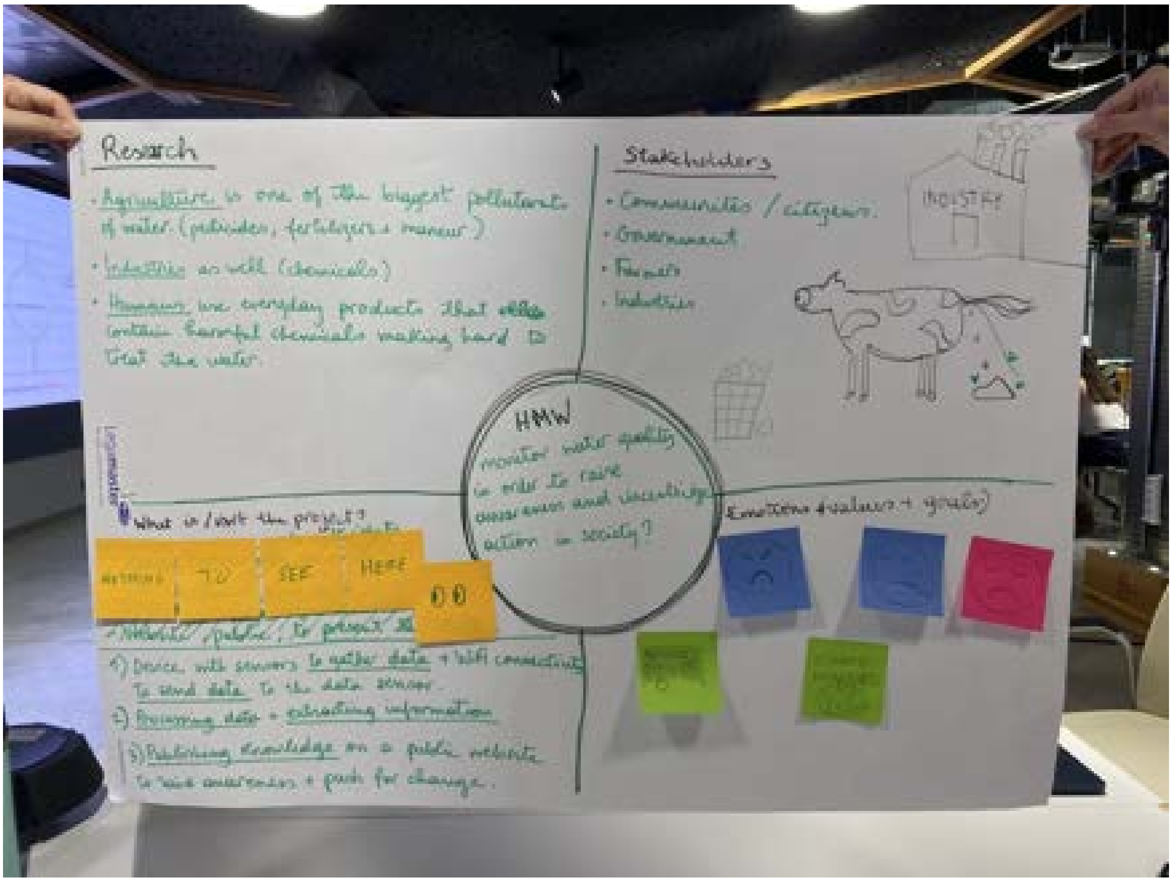
Research suggested that current water treatment plants are too centralized, making communities dependent on wealthier areas and rendering plants too costly for small, isolated neighborhoods. This idea led us to consider decentralized solutions as part of our approach.

After discussing these ideas, we realized that many were too general or idealistic, particularly since we lacked a clear understanding of the wastewater treatment process. We decided to first learn about the process and then develop more relevant and specific ideas.

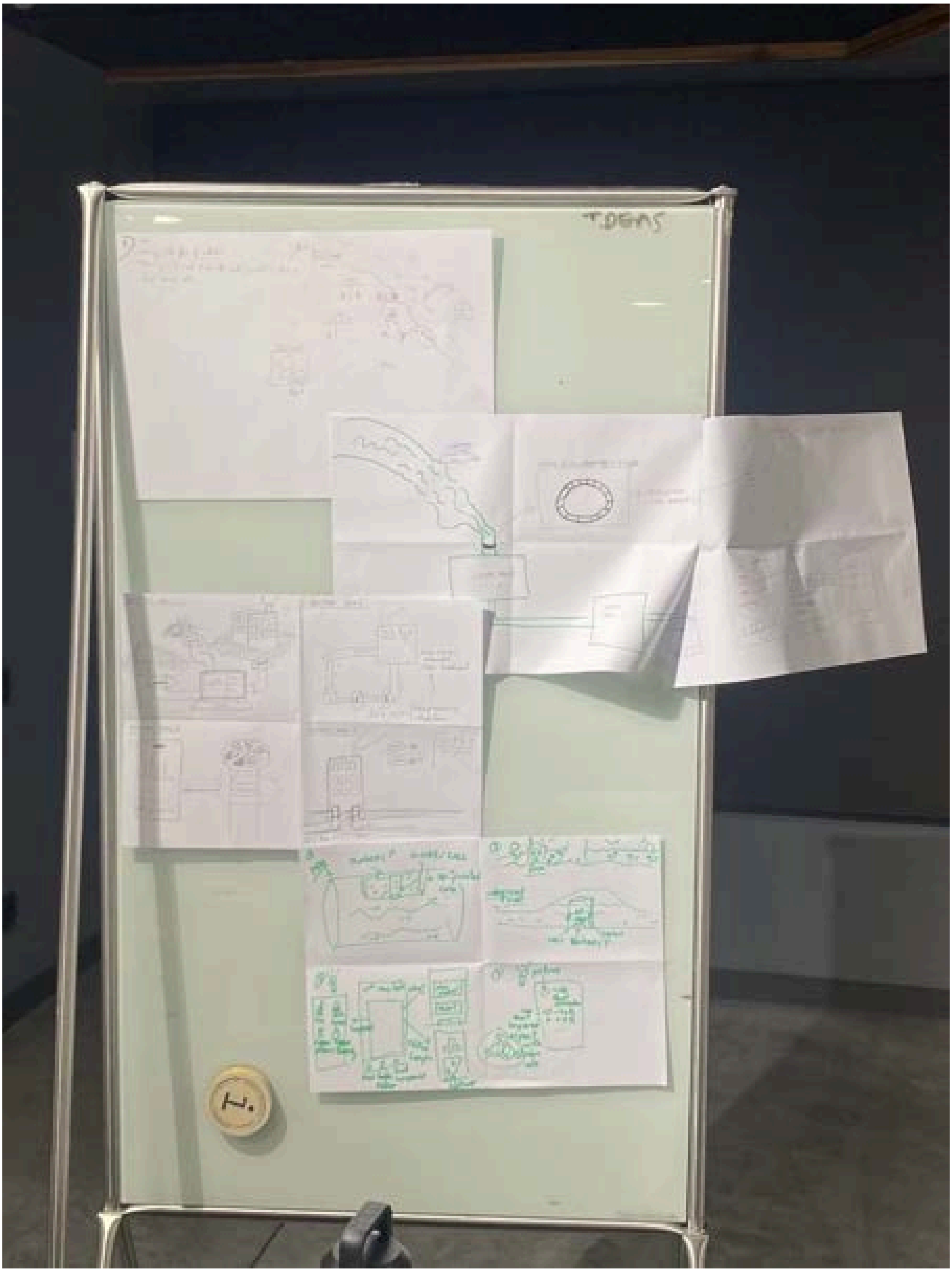


3. Abandoned ideas

After a systematic study of the wastewater treatment process, more research and more brainstorming, our project initially aimed to collect and analyze wastewater data to inform citizens about their country's health status and drive government action. However, recognizing the need for more tangible outcomes and efficient resource allocation, we decided to pivot our approach. Instead of focusing on data collection and awareness, we are now directing our efforts towards direct intervention measures that address critical issues such as wastewater treatment and energy shortages. This strategic shift allows us to make a more concrete impact with our resources, ensuring efficient allocation and effective intervention initiatives to improve public health and environmental quality.



Research
Agriculture is one of the biggest pollutants of water (pesticides, fertilizers + manure)
Industries as well (chemicals)
Humans use everyday products that contain harmful chemicals making hard to treat the water.
Stakeholders
Communities / citizens
Government
Farmers
Industries
INDUSTRY
HMW
monitor water quality in order to raise
awareness and
action in society?
What is/isn't the project?
TO
SEE
HERE
1) Device with sensors to gather data + WiFi connectivity to send data to the data server.
2) Processing data + extracting information
3) Publishing knowledge on a public website to raise awareness + push for change.
Emotions (values + goals)



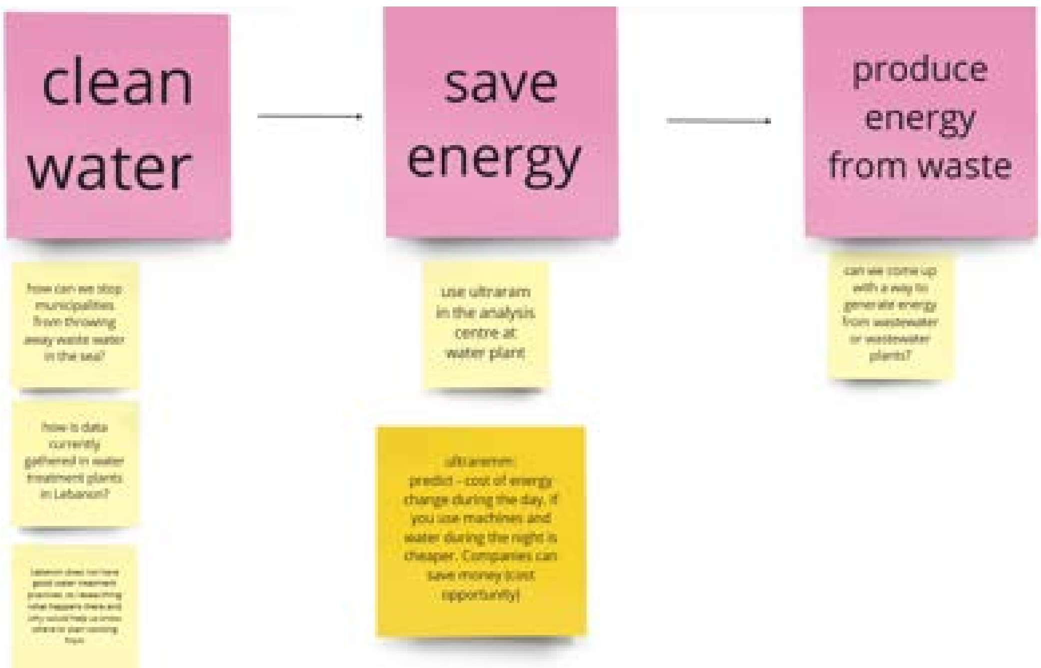
Problems encountered and solutions

During our project, we encountered significant challenges that led us to completely change our solution. Initially, we were excited about an educational and visualization app to inform citizens about wastewater and drive government action. However, this method proved ineffective in addressing the immediate issues of wastewater treatment and energy shortages and it was beyond our ability to reach to the government directly. This realization brought a moment of sadness, as we had invested considerable time and effort into this idea.

Recognizing the need to start over late in the development process, we had to quickly reorganize to meet our deadlines. We brainstormed new ideas and tackled numerous questions and doubts about our approach. Our new direction focused on direct intervention measures, leveraging advanced technologies to tackle wastewater treatment and energy production problems more effectively.

For instance, we shifted our focus to developing a solution involving sensors in the city sewage system to monitor wastewater, inspired by the earlier idea of household filters. We also incorporated AI optimization to enhance energy efficiency and data analysis, using ultraram technology. This required gathering and analyzing large amounts of real-time data, which was challenging but necessary to ensure our solution's robustness.

A major turning point was realizing the importance of decentralizing the water treatment process. This insight helped us design a scalable solution capable of addressing different communities' needs, including small, isolated neighborhoods. By integrating renewable energy sources, such as anaerobic digestion to produce biogas, we ensured our solution was environmentally sustainable.



Throughout this process, we maintained open communication and collaboration within the team, ensuring that everyone's ideas were considered and critically analyzed. By overcoming these challenges, we developed a more effective and innovative solution that addressed the core issues we set out to solve.

In summary, discarding our initial idea was difficult, but it led us to a more viable and impactful solution. This experience taught us the importance of flexibility, collaboration, and thorough analysis in problem-solving. Our final solution, which involves advanced sensors and AI-based data analysis to monitor and optimize wastewater treatment processes, along with renewable energy integration, allows us to make a concrete impact on public health and environmental quality.

Prototyping

Video prototype

Once our solution was clear and we knew the steps to follow, we prototyped it by requesting an animated video about it. We wrote a two minute long script and described the scenes that would accompany it.

Then, the animator drew them based on a set of reference images we shared with him. The script was read by a professional voice actor, who provided an elegant result to the video.

We targeted the video to academic professionals, researchers and students, with the aim of presenting the problem we had identified and the solution we provided. It can be watched freely at
https://drive.google.com/file/d/1euvhUlA8iqkPSsJEcpQ2vh_g6EV390Ku/view?usp=sharing

Poster

The poster for our wastewater-to-energy project is designed to clearly illustrate how we generate energy from wastewater through a detailed life cycle diagram.

1. Title and Introduction: “Creating energy and perfecting the wastewater cycle” briefly summarizes the whole idea of our project. We really wanted to make sure that all of this completed the cycle of water.

2. Lifecycle Diagram: The core of the poster is an illustration showing the entire water cycle:

- Bacteria measuring sensors: Shows where we put the sensors in the first step, in the pipes of the wastewater coming from the community (industries, houses, agriculture…).
- Data analysis center: Highlights the stage where our technology, including microbial fuel cells and AI optimization, is integrated to extract energy. The sensors we put in stage 1 are collecting data and sending it to the data centers where they are optimally analyzed and stored with ULTRARAM.
- Energy positive treatment: Shows the point at which energy is harvested from the treated water. All this is made possible and optimized from the technologies we introduced to the cycle.
- Energy generation: The energy generated from the anaerobic digestion plants helps create electricity and power the wastewater plants. Completing the cycle!

3. Visual and Textual Clarity: The diagram is supplemented with concise labels and annotations to explain each stage and the role of our technology.


AquaIntelligence
Creating energy
and perfecting the wastewater cycle
Community
1
2 Data analysis center
AI trained to:
- **predict** micro-organism flows for real-time adaptation
- **identify** high energy production areas
Collection system
Wastewater treatment plant
Electricity generation
methane
biogas
3 Energy-positive treatment
Anaerobic digestion plants, producing biogas from wastewater sludge.
4 Energyyyy
Powering the wastewater plants and more!


AquaIntelligence
Creating energy from wastewater
Davide
Grady
Matilde
IED
esade

References

W.P.F. Barber,
Thermal hydrolysis for sewage treatment: A critical review,
Water Research,
Volume 104,
2016,
Pages 53-71,
ISSN 0043-1354,
https://doi.org/10.1016/j.watres.2016.07.069

D.Jaya Prasanna Kumar, Ranjeet Kumar Mishra, Sampath Chinnam, Prakash Binnal, Naveen Dwivedi,
A comprehensive study on anaerobic digestion of organic solid waste: A review on configurations, operating parameters, techno-economic analysis and current trends,
Biotechnology Notes,
Volume 5,
2024,
Pages 33-49,
ISSN 2665-9069,
https://doi.org/10.1016/j.biotno.2024.02.001

Aniket Naha, Reetika Debroy, Dhrubjyoti Sharma, Maulin P. Shah, Soumitra Nath,
Microbial fuel cell: A state-of-the-art and revolutionizing technology for efficient energy recovery,
Cleaner and Circular Bioeconomy,
Volume 5,
2023,
100050,
ISSN 2772-8013,
https://doi.org/10.1016/j.clcb.2023.100050

Hodgson, Peter D.; Lane, Dominic; Carrington, Peter J.; Delli, Evangelia; Beanland, Richard; Hayne, Manus;
ULTRARAM: A Low-Energy, High-Endurance, Compound-Semiconductor Memory on Silicon,
Advanced Electronic Materials,
Volume 8,
2022,
2101103,
ISSN - 2199-160X
https://doi.org/10.1002/aelm.202101103

https://h-cube.eu/

Zhang, B., Xu, X. & Zhu, L.
Activated sludge bacterial communities of typical wastewater treatment plants: distinct genera identification and metabolic potential differential analysis.
AMB Expr 8, 184 (2018).
https://doi.org/10.1186/s13568-018-0714-0

Harirchi S, Wainaina S, Sar T, Nojoumi SA, Parchami M, Parchami M, Varjani S, Khanal SK, Wong J, Awasthi MK, Taherzadeh MJ. *Microbiological insights into anaerobic digestion for biogas, hydrogen or volatile fatty acids (VFAs): a review*. Bioengineered. 2022 Mar;13(3):6521-6557.
https://doi.org/10.1080/21655979.2022.2035986

Detection of microorganisms using terahertz metamaterials
S. J. Park, J. T. Hong, S. J. Choi, H. S. Kim, W. K. Park, S. T. Han, J. Y. Park, S. Lee, D. S. Kim, and Y. H. Ahn
Scientific Reports, 4(1):4988, 2014
https://doi.org/10.1038/srep04988

Ahmad Pourmovahed, Terance Opperman and Brenda Lemke
Performance and Efficiency of a Biogas CHP System Utilizing a Stirling Engine
International Conference on Renewable Energies and Power Quality (ICREPQ'11)
Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011
https://www.icrepq.com/icrepq'11/288-pourmovahed.pdf

Hamawand, I.
Energy Consumption in Water/Wastewater Treatment Industry—Optimisation Potentials
. Energies 2023, 16, 2433.
https://doi.org/10.3390/en16052433
https://www.aquatechtrade.com/news/wastewater/essential-guide-energy-from-wastewater

Density of wastewater:
https://www.aqua-calc.com/page/density-table/substance/sewage-coma-and-blank-sludge

Methane per g of wastewater:
https://www.sciencedirect.com/science/article/pii/S2665906924000047?via%3Dihub#tbl3

cal/g of methane: https://cngeurope.com/fuel-calorific-values/

Methane density: https://en.wikipedia.org/wiki/Methane

Liters of wastewater/person/day:
https://www.wte-ltd.co.uk/wastewater-amounts-in-the-home.html

Price solar panels:
https://www.forbes.com/home-improvement/solar/cost-of-solar-panels/

Price CHP:
https://understandingchp.com/chp-applications-guide/6-8-rules-of-thumb-for-chp-engineering-and-installation-costs/

Energy consumption/person/day in Lebanon:
https://www.worlddata.info/asia/lebanon/energy-consumption.php

Wastewater production/person/day:
https://www.wte-ltd.co.uk/wastewater-amounts-in-the-home.html

AI in wastewater treatment:
https://www.sciencedirect.com/science/article/pii/S0045653523014303

Metamaterials: Detection of microorganisms using terahertz metamaterials | Scientific Reports (nature.com)

Already operating energy-positive plants:
https://www.aquatechtrade.com/news/wastewater/essential-guide-energy-from-wastewater

Anaerobic digestion: **A comprehensive study on anaerobic digestion of organic solid waste: A review on configurations, operating parameters, techno-economic analysis and current trends - ScienceDirect**

Decentralized Wastewater: **Resources | Free Full-Text | Integrated, Decentralized Wastewater Management for Resource Recovery in Rural and Peri-Urban Areas (mdpi.com)**

Decentralized Wastewater: **Wastewater treatment in 2050: Challenges ahead and future vision in a European context - PMC (nih.gov)**