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ERE1.5 – Sustainable Food Systems Transformation in the face of Environmental Change and Water Shortage

Leveraging renewable energy solutions for distributed urban water management: The case of sewer mining

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Motivation: Tackling the everlasting issue of water scarcity

Main drivers of water scarcity:

- Population growth
- Rapid urbanization
- Economic crisis
- Climate change

→

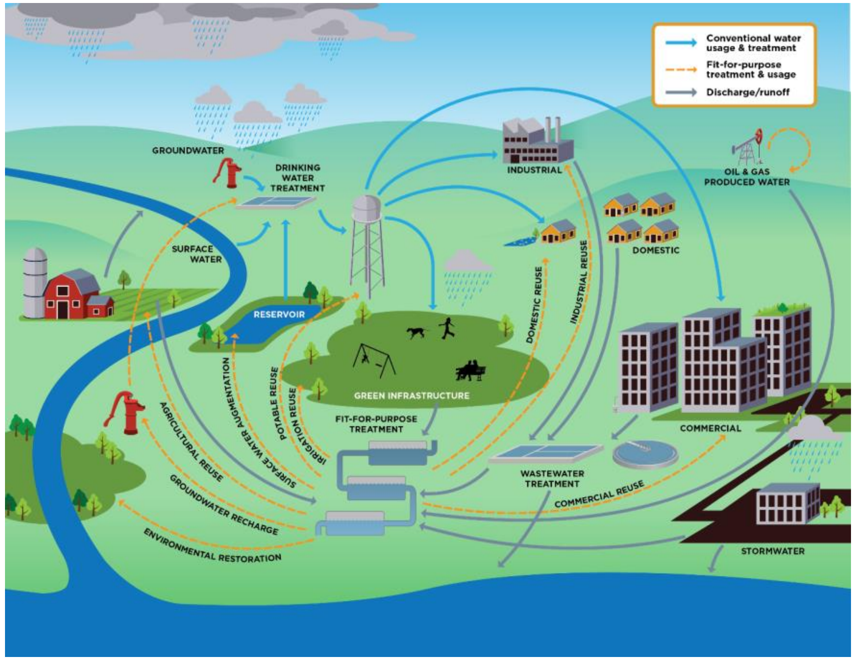
Impact of water scarcity:

- Reduction in water availability
- Deterioration of water quality
- Seasonal water shortage

How can we tackle water scarcity?

Water scarcity has constituted an urgent need for innovative practices and solutions that are **distributed**, **autonomous**, **adaptable**, and **scalable**.

Among such solutions, **water reuse**, as key component of the **circular economy** scheme, has become an attractive option for keeping resources within social or industrial systems for as long as possible, while extracting additional value from them.



Source: F Hidayat and O C Dewi 2022 IOP Conf. Ser.: Earth Environ. Sci. 1058 012009.

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The case of Sewer Mining

Sewer mining (SM) technology is a mobile wastewater treatment system in containers, which is able to extract wastewater from local sewers, **treat it directly** and **reuse at the point of demand** in dense urban environments. It produces high quality reclaimed water for irrigation of green areas, aquifer recharge, and other urban uses. The unit consists of a membrane bioreactor unit (MBR) and a UV disinfection system.

Description of the process:

1. The sewerage is extracted through pumps to fill a buffer tank;
2. The unit is fed with wastewater from the buffer tank through a pump. The raw sewerage is transferred to a series of tanks where treatment processes take place;
3. The permeate overflows and passes through the UV disinfection unit, with the final product flowing naturally in the storage tank and towards irrigation.

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The energy footprint of Sewer Mining units

Sewer mining units, compared to centralized water treatment plants, provide greater **flexibility** and **autonomy**.

By reducing sewerage loads, they ensure better hydraulic conditions across conveyance systems, also decreasing pumping and treatment costs.

A critical operational issue of SM units is the **cost of electricity**, due to power consumption across all their components (pumps, MBRs, disinfection), which may constitute their economic feasibility rather questionable.

The pumping cost can be minimized through an optimal placement of the unit with respect to the sewage network.

In light of **minimizing** the remaining (and definitely most important) **energy footprint** of SM operation, the following question is raised:

"***Within the context of circular economy, could local energy production from renewables reduce the unit's grid dependence?***"

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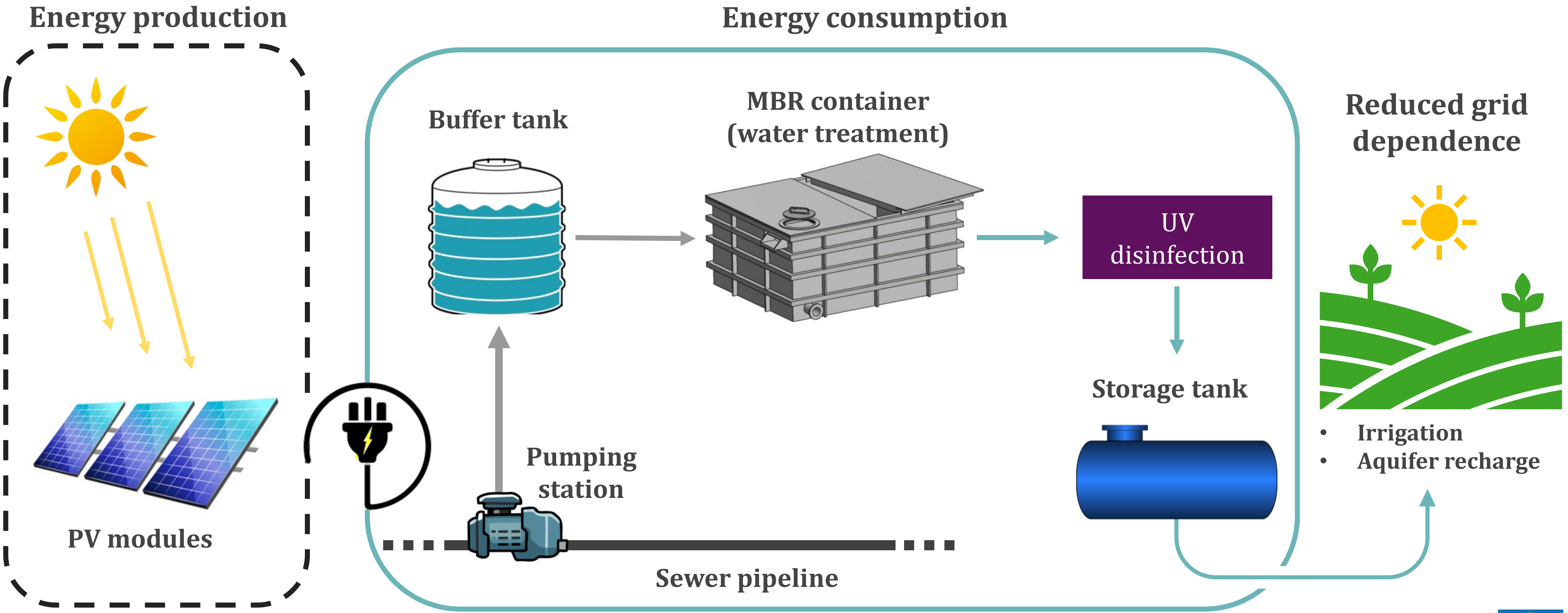
The concept of solar PV integration within Sewer Mining systems



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Pilot implementation in Athens Tree Nursery, Greece

Athens consists of a very dense urban environment, with few green spaces. Water distribution has become a significant challenge, especially during the summer months, given that it is supplied from 300 km away. The Urban Tree Nursery of Athens acted as a pilot site for the experimental operation of a sewer mining unit.

- Prior to the unit's installation, the nursery was irrigated with potable water provided by the Water Supply and Sewerage Company of Athens;
- The unit is designed to treat **25 m^3** of water **daily**;
- The surrounding gardens are then irrigated with the treated water.

Overview of operational improvements

After trials and fine turning, a set of operating rules was implemented to increase the unit's overall efficiency, resulting to a **32% reduction** of its average power consumption (from 120 kWh to 82 kWh) by modifying the motor to operate **intermittently** in 10 minutes on – 4 minutes off cycles.

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The proposed methodological scheme

Following the previous question, we consider **the integration of solar photovoltaics** a potential solution and we further investigate it through different scenarios.

The scenarios are formalized in a simulation context, accounting for meteorological processes (i.e., solar radiation, temperature) as well as the unit's energy consumption.

Inputs → **Simulation** → **Outputs**

Inputs

- Solar radiation
- Temperature
- PV module characteristics (area, power capacity, efficiency, thermal coefficient)
- Economic data (electricity cost, PV cost)
- Unit energy consumption

Simulation

- Hourly simulation of solar power production (15 years)
- Assessing PV performance for various degrees of power autonomy based on synthetic daily energy demands
- Investigation of 44 commercial panels (conventional – high efficiency)

Outputs

Optimal PV scenarios under two criteria:

- Least PV occupied area
- Least cost (investment and operational)

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Simulation assumptions

- The **energy consumption data** during the two-year operation of the unit indicate that:
  - the daily energy consumption ranges between 76 to 88 kWh;
  - the sharing between day and night tariffs is 70/30% (practically, these ratios are constant);
  - the largest portion of energy is consumed by the wastewater treatment components (blowers, a/c unit) and is practically constant.
- Considering these facts, the following **assumptions** are made in simulations:
  - the energy demand is handled as a **random process**, derived by a normal distribution that is properly adjusted to reproduce the aforementioned range of the observed consumption;
  - when the simulated solar energy production exceeds 70% of the daily demand, the system is considered as **fully autonomous** during day hours, while any surplus quantity is distributed back to the grid (**net metering**);
  - the **nightly energy** demand, i.e., 30% of total one, is covered by the electricity grid;
  - the **treated water volume** is fixed to 25 m^3/d;
  - all **economic quantities** (e.g., electricity prices, panel costs) are based on present day data.

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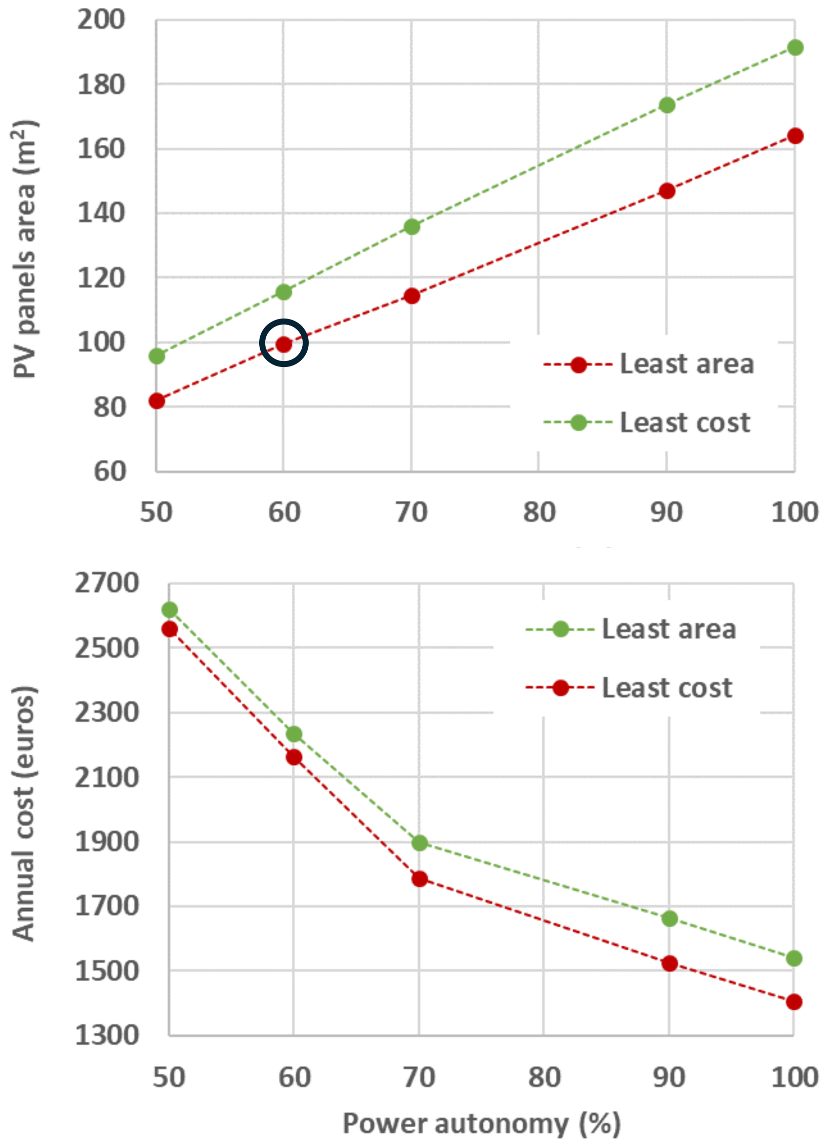
The trade-off between PV area and cost

- Two design optimization scenarios are investigated, accounting for least-cost and least-area criteria;
- Our analyses reveal interesting **trade-offs** between the area captured by the PV panels and the aggregated annual cost, estimated as the sum of depreciated installation cost of PVs and cost of electricity (grid supply);
- As expected, as the area captured by the PV panels increases, higher power autonomy (defined as the ratio of daily energy production to daily demand) is ensured;
- Notably, **the increase of PV capacity is counterbalanced by the significant reduction of electricity cost**. In this vein, as the power autonomy increases, local production becomes more attractive than the grid supply, in economic terms;
- As a best compromise solution, we also assess a **compact** layout, covering the SM unit's footprint with PVs on a pergola placed above it (for an area of ~100 m^2 and a ~60% power autonomy).



Graphs of the cost and PV panel area with respect to SM unit power autonomy for the two optimization scenarios (least area, least cost).

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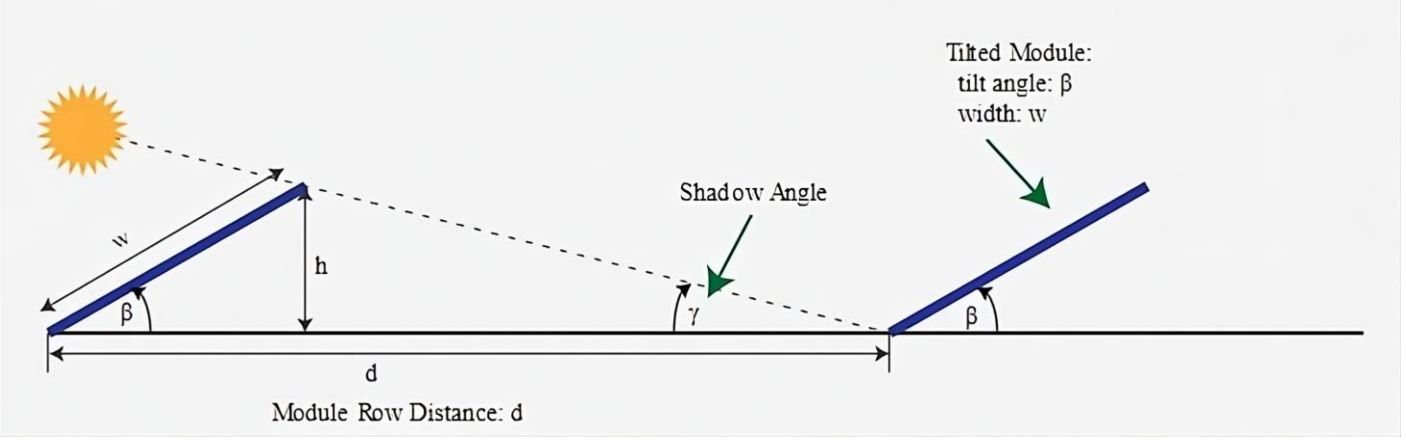
Tilted PV modules – Advantages and layout constraints

All previous scenarios consider horizontal panels. Alternatively, tilted PVs are also examined for the previous scenarios at a fixed angle of 31°, which is the optimal angle for the pilot site.

All investigated scenarios result to a **2-6% reduction of cost** and a **10% reduction in occupied area**, due to the increased energy yield. However, this area reduction only occurs if the PV array is placed in a single row. Tilted PV rows need to be further distanced to prevent shading effects, which result to power curtailment (Osmani *et al.*, 2021).

Indicatively, accounting for the solar altitude during the summer months, a two-row layout of tilted PV's would lead to a **30% increase** in occupied area, compared to that of non-tilted ones.



Source: Osmani *et al*, 2021.

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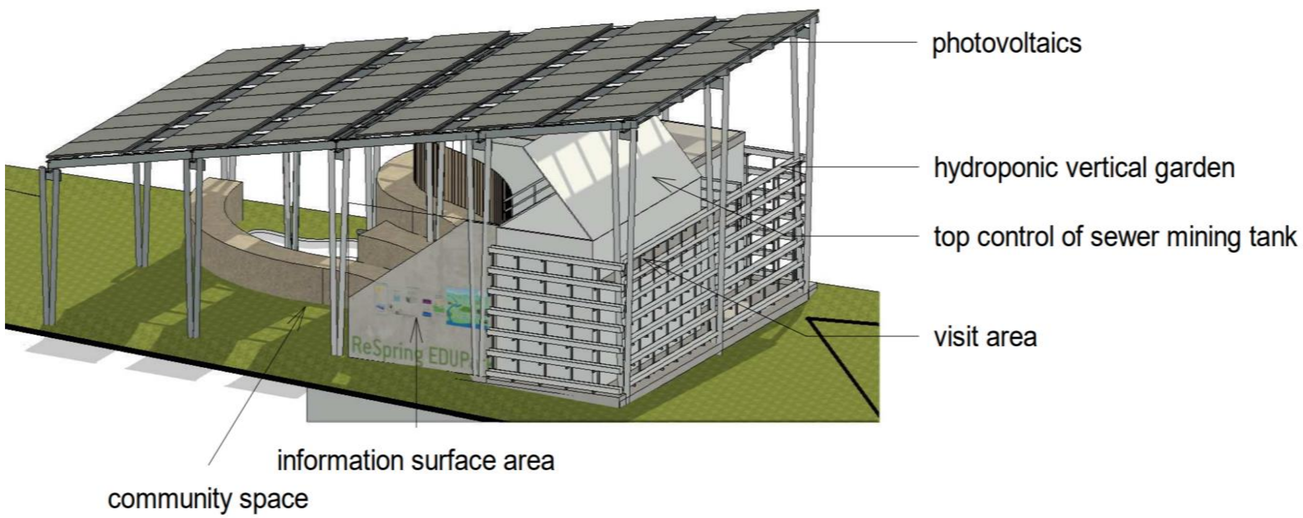
An architectural perspective

An important design aspect to consider is **aesthetics**, which is inextricably related to **social acceptance**.

An optimal **architectural design** allows for the harmonic integration of SM units and PVs within urban green spaces, also resulting to reduced irrigation needs due to **shading effects**, when PVs are placed above plants and crops (Roxani *et al.*, 2023).



The architectural schematic and the photorealistic representation images of the SM unit are part of an ongoing study concerning the installation of such a configuration in Markopoulo, Athens.

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Lessons learnt and conclusive remarks

- The integration of renewables within water reuse solutions constitutes a very promising prospect for dense urban environments, under the triptych of **water saving**, **energy efficiency** and **circular economy**.
- Taking as example the harnessing of **solar energy** as a means of **reducing the grid dependence of sewer mining units**, we tested different PV technologies (conventional / high efficiency) in order to identify optimal layouts from an **economic** and **spatial** perspective.
- Our analyses revealed the existence of **trade-offs** between the **occupied area** of PV panels and the **total cost**. In particular:
  - ✓ The **least area** scenarios require the installation of high-efficiency modules, which come at an increased cost.
  - ✓ On the contrary, the **optimal cost** scenarios opt for conventional, cost-effective modules, yet require larger occupied areas.
- The alternative of **tilted PVs** results to increased overall efficiency and reduced cost, yet imposes spatial constraints.
- All examined scenarios **favor the integration of PVs**, thus minimizing grid dependence.

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