SOL-DAZE: Smart Solar with Integrated Storage for Decentralized Autonomous Zero Emission Future. Techno economic analysis.

Mikel Martín[1], João Gomes[1], Sathish Kumar[2] and Miguel Lança[3]

[1] Högskolan i Gävle, Gävle (Sweden)

[2] MG Sustainable Engineering AB, Uppsala (Sweden)

[3] Instituto Superior de Engenharia, Lisboa (Portugal)

Abstract

This paper develops a techno economic assessment for the project named SOL-DAZE, a next-generation AI-driven microinverter that optimizes solar energy harvesting. The objective of this work is to verify the technical and economic feasibility of the project with respect to conventional PV systems, as well as briefly evaluating the environmental impact of the system. The method used consisted in conducting a cost analysis based on data given by experts or found in the market for a coastal city in central Sweden. Next, KPIs such as LCOE, ROI, NPV and Payback Period were calculated, and the CO2 emissions were determined, enabling comparison between SOL-DAZE and conventional PV for off-grid, hybrid and on-grid case scenarios. Later, sensitivity analyses were conducted reducing sodium-ion battery price, adjusting electricity price and changing location. Results of this study show that SOL-DAZE is a feasible alternative technically, economically and with less environmental impact. For the base scenario, an LCOE of 0.0503 € kWh^{-1} is obtained for SOL-DAZE, which compared to conventional PV's LCOE (0.0495 € kWh^{-1}) is a very competitive price. Furthermore, sensitivity analyses show that SOL-DAZE optimal location is places with low sun hours and high energy price, obtaining positive NPV values. When location was changed to Spain, SOL-DAZE's payback periods ranged between 6 and 10 years for hybrid and off-grid applications. It can be concluded that SOL-DAZE will not only bring advancements to the solar field but that it will additionally be more profitable in the appropriate context.

Keywords: *PV, battery, off-grid, hybrid, microinverter, Sweden, LCOE.*

Technical term	**Symbol/Abbreviation**	**Unit**
Artificial Intelligence	AI	-
Photovoltaic	PV	-
Direct Current	DC	-
Alternating Current	AC	-
Internet On Things	IOT	-
Maximum Power Point Tracker	MPPT	-
Peer-to-peer	P2P	-
Levelized Cost Of Electricity	LCOE	-
Return Of Investment	ROI	-
Net Present Value	NPV	-
Lithium-ion Battery	LIB	-
Sodium-ion Battery	SIB	-
European Union	EU	-
Key Performance Indicator	KPI	-
Nickel Cobalt Manganese	NCM	-

10.18086/swc.2025.05.16 Available at http://proceedings.ises.org

1. Introduction

Within the global energy context, renewable energies but also energy efficiency and green resources are taking on a relevant role. This is mainly due to the Paris treaty adopted by 196 parties in 2015, which aims to limit the increase in global temperature to 1.5 ºC above pre-industrial levels (United Nations, 2015). To achieve that, sustainable policies, widespread implementation of renewables and mostly zero net emissions technologies are needed. In the recent years, AI has become trending ever since OpenAI launched their chatbot ChatGPT, back in November 2022. This has led to a revolution in industry, AI has been predicted to be the most powerful ally for companies in the present and future.

The SOL-DAZE project aimed to develop a next-generation AI-driven microinverter that integrated battery storage, predictive analytics, and grid-interactive functionalities to optimize solar energy harvesting. The system enabled intelligent decentralized energy storage, real-time response to grid conditions, and dynamic peer-to-peer energy balancing among microinverters, also available to provide maximum self-consumption and customizable for off-grid via software.

Since the project encompassed a broad range of topics, the research mainly focused on the techno economic analysis. More specifically, it investigated the feasibility of the whole system (PV + 1 kWh Na-ion battery + microinverter) when compared to the costs of the traditional system, which accounted for a PV array, an inverter and all the components needed for DC and AC transportation. The system was based in Gävle, a coastal city in central Sweden.

The paper was conducted with a collaboration at MG Sustainable Engineering AB. It was coordinated with different partners such as RISE (Research Institute of Sweden), Uppsala University, GE4A, EXOBLOCK and the National Institute of Chemistry of Slovenia, each complying with their respective parts of the project.

1.1 Aims

The SOL-DAZE project sought to address key challenges in solar energy integration and provide solutions, including: reduction of grid curtailment issues by optimizing power export timing and storage, decentralized energy storage management, off-grid/hybrid/on-grid functionality, real-time maintenance prediction for solar panels using AI-based algorithm, MPPT tracking with quicker reaction time for the setpoint, fire and spark safety mechanisms with rapid shutdown functionality, cloud based controls avoiding several hardware that is required for storing and controlling locally, peer-to-peer data transfer with IOT based data transfer and quantum cryptography to protect the system from hacking, and digital passport of each solar panel and circularity details. These enable the system to be used by solar PV manufacturers to track the warranty and replacement, it can be used by recycling industry and allows direct billing system for energy as a service.

In order to solve those problems, the key objectives of SOL-DAZE are the following:

1. Develop an AI-optimized microinverter. Compatible with 500 W_p to 800 W_p solar panels, including 1/2-cell and 1/3-cell configurations. Include AI-enhanced MPPT tracking for real-time optimization.
2. Integrate modular battery storage. 1 kWh modular battery with IP68 protection for extreme environmental conditions. Use 80 % secondary or recycled resources for sustainability.
3. Enable intelligent energy balancing and grid resilience. Implement microinverter-to-microinverter communication for energy balancing during power outages. Support peer-to-peer energy exchange and off-grid capabilities.
4. Implement AI-driven, price-sensitive energy export. Real-time dynamic pricing adaptation to optimize grid export and storage. Reduce grid curtailment losses by 30 %.
5. Enhance safety and reliability: rapid shutdown for fire and spark incidents to improve safety. Extended inverter lifespan of 25 years, matching the battery’s approximate 10 000-cycle durability.
6. Develop a zero-touch cloud-based site onboarding system: fully automated, plug-and-play installation reducing manual setup efforts. No on-site configuration, all settings are optimized via cloud-based AI.

1.2 Approach

To achieve the aims outlined above, the study followed a structured techno economic analysis composed of both technical and economic evaluation and assessment. The analysis first defined SOL-DAZE, it specified its main components, being those solar PV modules, AI-driven microinverters, integrated 1 kWh sodium-ion batteries and the communicational software for P2P exchange. Key technical parameters such as energy efficiency, battery life cycle, system lifespan and resilience were evaluated based on the project's technical design, objectives and industry benchmarks. Nevertheless, the technical specifications are yet to be fulfilled by the partners of the project.

Following the technical assessment, an economic evaluation was conducted. This quantified capital expenditures, operational and maintenance costs, profitability, etc. Critical financial indicators were calculated, such as LCOE, ROI, NPV and Payback Period. Later on, a comparative analysis was made, comparing SOL-DAZE and conventional solar PV systems with and without batteries and for off-grid, hybrid and on-grid case scenarios.

Sensitivity analyses were also employed to explore the impact of different variables. This could include fluctuation in electricity prices, price reduction in components of the system, change of interest rates and others. Making a difference on the economic outcomes. The analysis provided an idea on how resilient SOL-DAZE was to these issues. All data was contextualized to reflect realistic Swedish market conditions, more accurately, to match Gävle's solar and energetical conditions, as well as electricity price statistics. This has been done since a possible testing site for the project could be the university of Gävle, Högskolan i Gävle.

By combining technical performance metrics with financial modelling, the approach aimed to deliver a comprehensive and realistic evaluation of SOL-DAZE's viability, helping guide both research direction and potential commercialization strategies.

2. Components

This chapter describes the components used for SOL-DAZE and what advantage they provide with respect to conventional components in PV.

2.1 Sodium-ion batteries

Most of batteries are composed of a cathode, anode, electrolyte and separator; each fulfilling one vital part of the process of the electron transfer. The anode is the negative electrode and the cathode the positive, when charging, the cathode will free its ions, and the anode will take them. During the discharge the contrary will occur. The electrolyte is the medium that allows the flow of ions. The separator is a layer that prevents short-circuits by letting the ions flow through but not the electrons.

In the recent times, with the development of portable electronic devices, lithium-ion batteries have become predominant. This has led to LIBs being present in all-types of applications, to which maybe other type of battery would be best, but it is not as developed as LIBs are (Delmas, 2018). SIBs are more suitable for larger stationary applications; the global sodium reserves are abundant (it can be extracted even from seawater), and the operating principle is the same as for LIBs.

Compared to regular lithium batteries, the use of sodium provides benefits in temperature range, safety and environmental impact. It works better in colder temperatures, it is less flammable than lithium and its extraction is less harmful for the environment, being sometimes a byproduct of industrial activities (Deshmukh, et al., 2025).

SIBs consist mainly of a layered oxide cathode, an anode composed of hard carbon, and the electrolyte and separator are made of the same materials used in LIBs (Deshmukh, et al., 2025). Currently they are being sold at roughly 85 \$ kW^{-1}, but it was predicted that in few years the cost could decrease drastically, down to 10 \$ kW^{-1} (Dominko, 2025).

2.2 Microinverters

Microinverters are the smaller version of the traditional string inverters. But unlike the string inverters, that are designed to manage loads of a string of solar panels in the conversion of DC to AC, microinverters do the conversion directly in each solar module.

That conversion by module is what makes microinverters more efficient overall for the solar PV array. Since shading effects, dust or any blocking in one solar panel can be isolated easily and does not drag the efficiency of the complete system.

In Figure 1 a full-bridge microinverter of this type is shown. This type of inverter is used in most cases.

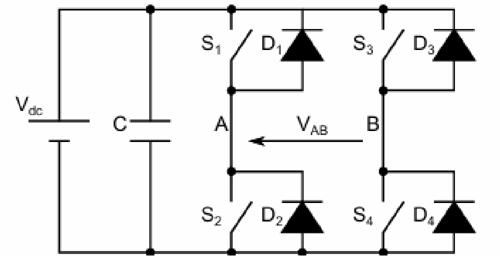

Figure 1: Schematic of a full-bridge microinverter (Kortabarria & Zabala, 2024).

When applied in PV, each solar panel is equipped with its own microinverter, meaning that not only is the conversion done individually, but also that each panel gets its own MPPT, enhancing the total efficiency (Chiu, et al., 2012). The use of microinverters leads to many benefits, listed next:

- Prevents significant losses due to shading effects, dust or inoperability of individual solar panels. Therefore, generation is increased expecting a final output between 5-25 % higher (Solar, 2020).
- Each panel is individualized, making faulty panels easier to find.
- Microinverters allow emergency shut-down at module level, improving the systems overall safety.
- Flexibility in design is also a benefit, making them suitable for complex roof shapes or with limited space. Additionally, their modularity and scalability make future expansion of the solar array feasible in a straightforward process.
- Microinverters offer longer lifespans (25 years) than string inverters (10-12 years) and are clearly reflected in the warranty periods offered by selling companies (Solar, 2020).

However, microinverters have some disadvantages such as the maintenance requirements, needing access to the roof every time some replacement needs to be made. Moreover, the cost per Watt in comparison to string inverters is still higher, around 20-30 % more expensive, but it might as well be mitigated with the expanded lifespan (Solar, 2020).

Figure 2 shows a real-life example of microinverters applied in solar PV modules. It can be appreciated how each panel has its own microinverter, making them independent from each other.

Figure 2. Microinverters real application example (Home Energy, 2025).

3. Methods

3.1. Study object, tools and scenarios

The initial step was defining the study object. This referred to the project SOL-DAZE, conducted in collaboration with MG Sustainable with intention of getting funding from the EU program *EIC Pathfinder*. This funding program gives a maximum of 3M € for the *EIC Pathfinder Open*, the call to which the project can apply. The project aimed to create an AI-driven microinverter for solar PV with integrated storage for decentralization. MG Sustainable did not actually develop any of the technologies, it coordinated the project, managed the partner companies that develop each technology, and tested the prototype of the system.

Once the study object was clear, the KPIs could be defined. The parameters were the LCOE, ROI, NPV and Payback period. These parameters allowed the project to have a perspective on the performance of the system on the long term, the economic effort to make and to have an estimated time in which economic benefits were obtained, if they were obtained at all. Additionally, by depicting these KPIs in charts and figures, a visual answer could be obtained for each case scenario.

Knowing the KPIs that were going to be useful, the different case scenarios must be defined, which served as common ground to make a comparison between systems and conditions. The different scenarios considered were off-grid, hybrid and on-grid. Additionally, a specific case study would be developed powering a desalination plant developed by Desolenator B.V., illustrating large-scale integration potential.

3.2 Technical design of the system

The technical design of the system accounted for the components of the system, their technical specifications and the schematic of the system. The main components of SOL-DAZE have already been presented: a solar PV module, with its microinverter and a battery inside a casing; all connected with their corresponding wires and auxiliary components.

The technical specifications referred to the power of the system, the efficiency, life cycle, etc. It ranged from the electrical specifications of current and voltage for the microinverter or battery capacity needed, to the charge cycles the battery could hold.

Lastly, the schematic of the system referred to how everything was connected, and how it should work. In Figure 3, the mentioned schematic is depicted, showing how the solar module was connected to the microinverter, which tracks the maximum power point and compared information with the AI-driven algorithm and database for when to store energy in the battery, use it in the household or sell it to the grid, depending on the case scenario.

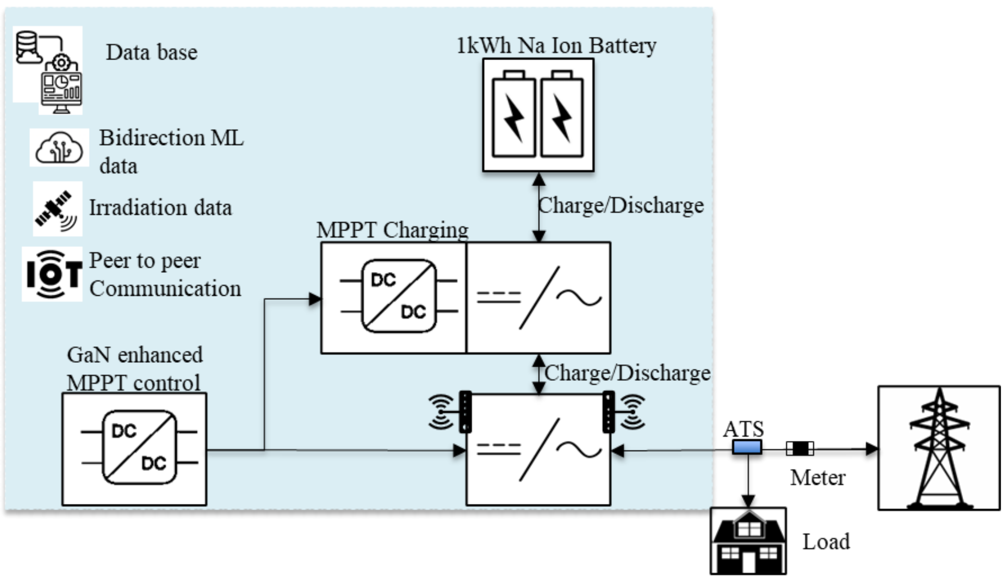

Figure 3: Schematic of the system

For enabling a levelled comparison, a facility with the same amount and model of solar modules was designed.

The power of the facility was 14.4 kW_p, composed of 24 bifacial panels with 600 W_p power each. Since one of the possible test grounds of the project was Högskolan i Gävle, the sun hours data was taken from there, being 997 hours of full load annually for solar PV in Gävle (Solargis, et al., 2016). The battery capacity was estimated as according to the project, 1 kWh per solar module, making it a total of 24 kWh of available electricity storage. This battery will be placed alongside the solar module and the microinverter, attached to the roof and properly protected.

Additionally, the consumption of the system was estimated as the total produced. This meant that if in total 14.357 MWh were produced, that same quantity would be consumed, so the sizing of the system was considered as 1:1. Nevertheless, due to curtailment issues in big production times and insufficient production in winter, electricity would have to be purchased from the grid or the system would have to be overdesigned for off-grid cases.

3.3 Cost analysis

Cost analysis was divided into investment costs and operational and maintenance costs. Investment costs or CAPEX accounted for the initial cost of the solar module, microinverter, battery, casing, mounting system and auxiliary elements, as well as for the installation costs and software and control costs. Operational and maintenance costs or OPEX referred to the periodical substitutions of elements, maintenance and monitoring and software costs. Depending on the nature of cost, some KPIs were affected more than others, giving a general overview of the project.

In the cost analysis, the initial investment was broken down for each component of the system. Economic support from the Swedish Government was included. This involved a 19.40 % reduction on the initial investment for all components related to the PV facility and a 48.5 % reduction in storage components such as batteries and casings. Apart from that, an additional 9 % could be deducted from the total investment (Stone, 2023).

The project was aimed for a lifetime of at least 25 years, that is why all the calculations were done with that reference in time. Additionally, the interest rate was set to 2 %, aligning and rounding it with the Euribor Index for April 2025 (Media, 2025). For the exported excess electricity price, the market price was taken from zone SE3 where Gävle is located. To get a yearly reference, monthly data from 2024 was taken and it is shown in Table 1, along with the annual average price (Pool, 2025). The average price for 2024 was 0.03577 € kWh^{-1}. Lastly, the billable price was taken from the last half of year 2024, being that value 0.204 € kWh^{-1} (SCB, 2025). The billable price refers to the price that the customer pays for electricity. This includes not only the market spot price at different times of the day, grid fees and taxes.

3.4 Profitability calculations

Profitability calculations are subjected to variable costs and unforeseen circumstances. But KPIs such as LCOE, ROI, NPV and Payback periods can provide very accurate results that vary on the real profitability by little. Next, the equations for the mentioned parameters are shown.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}} \qquad (eq. 1)$$

LCOE: Levelized Cost of Electricity (€ kWh^{-1})

I_0 Investment expenditure (€)

A_t Annual total cost (€) per year t

$M_{t,el}$ Produced amount of electricity (kWh per year)

i Interest rate

n Economic lifetime (years)

t Year of lifetime (1, 2, … n)

$$ROI = \frac{Profit - I_0}{I_0} \cdot 100 \qquad (eq. 2)$$

ROI: Return of Investment (%)

I_0 Investment expenditure (€)

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \qquad (eq. 3)$$

NPV: Net Present Value (€)

R_t Net cash flow at time period t (€)

i Interest rate

t Year of lifetime (1, 2, … n)

The comparison was made between SOL-DAZE's system and the electricity network. SOL-DAZE's systems were fitted in quantity and power so that it matched a normal sized solar array. In SOL-DAZE, each component of the system was considered and, in the network, every component such as string inverters and combiner boxes were included.

The main difference, though, was between scenarios with or without batteries and scenarios that exported electricity to the grid or not. It was estimated that on-grid systems with no storage capacity exported between 50 % and 70 % of the produced electricity to the grid. In the case of a system with batteries, self-sufficiency increased between 20 % and 50 %, depending on the storage capacity and consumption profile (Nyholma, et al., 2016). This meant that between 0 % and 50 % would be exported to the grid. That was the reason that buying prices from electric companies to particulars were important.

In order to use precise values for calculations, in Table 1 the percentages that were used are shown. Mean values were taken both for conventional systems with and without batteries and for SOL-DAZE, the 30 % improvement in curtailment issues was applied.

Table 1: Values considered for calculations

System type	Export
Conventional with no storage	60%
Conventional with storage	25%
SOL-DAZE	17,5%

3.5 Sensitivity analysis

Depending on the results that the comparison and the profitability analysis provide, the relevance of the different sensitivity analyses changed. The sensitivity analysis provided SOL-DAZE with a new perspective on how resilient the system can be to upcoming changes or unexpected events. It will also provide with new commercialization opportunities, depending on location factors or cost fluctuations.

Firstly, the sensitivity analysis considered a change in the cost of sodium-ion batteries. At the moment, their cost laid around 75-80 € kWh^{-1}, but with enough investigation and development, in the upcoming years it could get down to approximately 8 € kWh^{-1} (Dominko, 2025).

Secondly, electricity price fluctuations were taken into consideration. The billable electricity price considered was the one for the second part of year 2024 in the Swedish energy sector SE3, to which Gävle belonged. The half year taken as reference, 2024, was the among the lowest for the 3 last full years, that is why taking the average price for the last 3 complete years would result in a much more accurate electricity price. It is worth mentioning that these prices will be affected by the 2022 energy crisis, but scenarios like that must be considered if resiliency wants to be checked on SOL-DAZE. That average price for the timespan 2022-2024 was 0.227 € kWh^{-1}, being more than two times the used (SCB, 2025).

Last but not least, a third sensitivity analysis was conducted setting the place for research in Spain instead of Sweden. The energy requirement was kept constant and all the elements in the cost analysis too. The main change was in the sun hours and in the electricity price. Solar PV full load hours in Spain doubled the ones in Sweden, with an average between 1900 and 2000 h (Consultancy.eu, 2023). Moreover, the average price of electricity in Spain for year 2024 was 0.229 € kWh^{-1} (Eléctrica, 2025).

Simplified, the sensitivity analyses were the following:

- Lowering sodium-ion battery price from 75 € kWh^{-1} to 8 € kWh^{-1}.
- Adjusting electricity price in zone SE3 to last 3-full-year average (0.227 € kWh^{-1}).
- Changing test site from Gävle to Spain, having different electricity price (0.229 € kWh^{-1}) and different sun hours (1950 h).

3.6 Desolenator case-study

To illustrate large-scale applicability, SOL-DAZE was modelled as the distributed power-conversion network of a 1,000 m^3 day^{-1} hybrid desalination plant developed by Desolenator B.V. The plant couples photovoltaic-thermal collectors and a water-to-water heat pump with a Multi-Effect Distillation with Mechanical Vapour Compression (MED-MVC) process. Each PVT collector integrates a SOL-DAZE inverter and 1 kWh sodium-ion module, forming a fully decentralised, autonomous energy network. Key process parameters are:

- Electrical demand ≈ 15 kWh m^{-3} (including 2.5 kWh m^{-3} for the heat pump).
- Thermal demand ≈ 7.5 kWh_{th} m^{-3}.
- PVT field area ≈ 17 300 m^2 (~ 9 300 modules).
- Stratified thermal storage ≈ 400 m^3 at 80 °C.
- Distributed sodium-ion storage ≈ 30 MWh for two-day autonomy.

3.7 Environmental impact

In order to study the environmental impact of SOL-DAZE with respect to conventional PV, the focus was put on the batteries. This was because every other element was the same (solar modules for example) or equivalent in environmental impact terms (microinverters and inverter). Additionally, the impact of every other element of the system was in the magnitude of g kWh^{-1}, while batteries stood in the magnitude of kg kWh^{-1} (Muhammad Tawalbeh, 2021).

To reduce environmental impact and gain energy capacity per kg, SOL-DAZE used sodium-ion batteries, while in current PV facilities, it was common to find lithium-ion NCM batteries being used for storage.

The CO_2-equivalent emissions for manufacturing sodium-ion batteries were 98.9 kg kWh^{-1} (Xin Lai, 2023). Since the designed facility was expected to store up to 24 kWh of electricity, the emissions for the complete system were 2373.6 kg CO_2. Sodium-ion batteries are still an emergent technology, focusing more on reducing costs to become more attractive to the market rather than lowering their carbon footprint.

On the other hand, lithium-ion NCM batteries' CO_2-equivalent emissions for manufacturing were 118.2 kg kWh^{-1} (Xin Lai, 2023). Once again, the system was designed with 24 kWh of capacity, elevating the final value of emissions to 2836.8 kg CO_2. Differently, lithium-ion batteries are already present in the market and currently, the main focus laid on lowering the environmental impact and improving efficiency and energy density.

4. Results

4.1 Technical results

The technical aspects of SOL-DAZE are out of scope for MG Sustainable Engineering AB. That is why many partners have been involved. These technical aspects have been elaborated in Table 2, where each partner is assigned a technical issue to be solved and the do ability and necessary time was asked.

Although the technical validation was focused on the 14.4 kWp reference system, the architecture was also tested in simulation for a hybrid off-grid desalination application (Desolenator B.V.). The distributed inverter-storage network maintained frequency stability and reduced energy curtailment by 15 %, confirming robustness for multi-energy, autonomous operation. The Levelised Cost of Water (LCOW) was estimated to be 0.6 € m^{-3}, achieving full carbon-neutral operation and avoiding ≈ 8 000 t CO_2 yr^{-1} compared with diesel-driven reverse-osmosis systems.

Table 2: Technical feasibility and deadline.

Work package Title	Lead Participant	Feasibility	Start Month	End Month
System Architecture and Embedded Control System Blueprint	RISE (Research Institutes of Sweden)	YES	M1	M18
Development and Parametrization of Sodium-Ion Battery Technology	NIC (National Institute of Chemistry)	YES	M3	M30
Development of Energy Management Logics and Intelligent Control Algorithms	UU (Uppsala University)	YES	M4	M28
Design and Validation of the GaN-Based Power Conversion Platform	RISE (Research Institutes of Sweden)	YES	M6	M32
Implementation of Secure Peer-to-Peer Communication and Coordination Protocols	Exoblock	YES	M6	M30
Integration of Safety Mechanisms and Auxiliary Hardware for Functional Reliability	UU (Uppsala University)	YES	M12	M30

4.2 Economical results

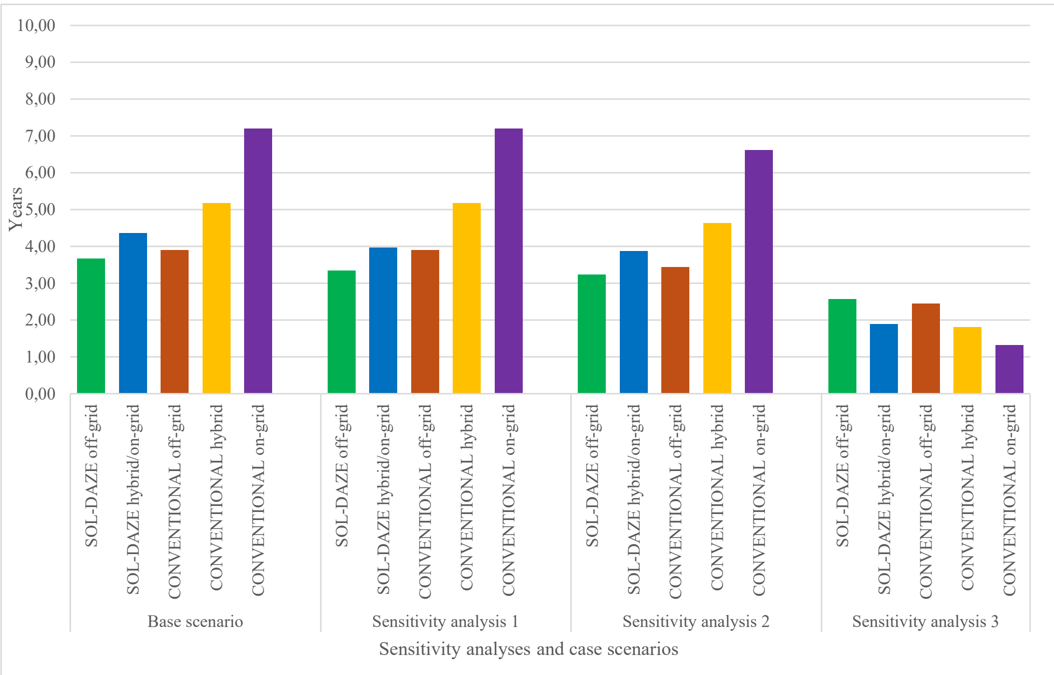

Figure 4: Payback Period for the base situation and each sensitivity analysis, for every case scenario.

In Figure 4, the Payback Period of the analyzed situations is shown. For cases that reach the top of the chart, it means that in the expected lifetime of the facilities, no payback is obtained. For the base scenario and the first sensitivity analysis, this situation happens where a PV system would not be worthy economically. For the second sensitivity analysis, interesting results are obtained, since payback periods are only obtained for SOL-DAZE's situations and conventional off-grid. Finally, when moved to Spain, favorable results are shown in all projects, being better in conventional PV.

In Table 3, the most relevant KPI´s are shown for each of the possible options. Similarly to the Payback Period, better results are obtained in the second and third sensitivity analyses, being the second sensitivity analysis where SOL-DAZE shows to perform better in comparison to conventional PV.

Table 3: KPI´s for the base situation and each sensitivity analysis, for every case scenario.

		ROI	NPV	LCOE
BASE SCENARIO	SOL-DAZE off-grid	711,11%	32.112,02 €	0,0537 €/kWh
	SOL-DAZE hybrid/on-grid	603,41%	25.848,15 €	0,0537 €/kWh
	CONVENTIONAL off-grid	658,27%	29.004,99 €	0,0495 €/kWh
	CONVENTIONAL hybrid	500,05%	20.056,59 €	0,0495 €/kWh
	CONVENTIONAL on-grid	377,84%	9.166,91 €	0,0386 €/kWh
SENSITIVITY ANALYSIS 1	SOL-DAZE off-grid	793,06%	32.795,42 €	0,0513 €/kWh
	SOL-DAZE hybrid/on-grid	674,48%	26.531,55 €	0,0513 €/kWh
	CONVENTIONAL off-grid	658,27%	29.004,99 €	0,0495 €/kWh
	CONVENTIONAL hybrid	500,05%	20.056,59 €	0,0495 €/kWh
	CONVENTIONAL on-grid	377,84%	9.166,91 €	0,0386 €/kWh
SENSITIVITY ANALYSIS 2	SOL-DAZE off-grid	802,56%	37.430,61 €	0,0537 €/kWh
	SOL-DAZE hybrid/on-grid	675,46%	30.038,55 €	0,0537 €/kWh
	CONVENTIONAL off-grid	743,77%	33.840,07 €	0,0495 €/kWh
	CONVENTIONAL hybrid	557,05%	23.279,98 €	0,0495 €/kWh
	CONVENTIONAL on-grid	408,65%	10.456,27 €	0,0386 €/kWh
SENSITIVITY ANALYSIS 3	SOL-DAZE off-grid	1003,65%	49.125,89 €	0,0275 €/kWh
	SOL-DAZE hybrid/on-grid	1355,14%	69.568,52 €	0,0275 €/kWh
	CONVENTIONAL off-grid	1034,93%	50.307,36 €	0,0253 €/kWh
	CONVENTIONAL hybrid	1396,39%	70.749,99 €	0,0253 €/kWh
	CONVENTIONAL on-grid	1922,91%	73.806,35 €	0,0197 €/kWh

4.3 Environmental results

The environmental impact in solar PV with storage was mainly focused on the batteries' life-cycle emissions, making the rest of the elements' emission negligible in comparison. The emission reduction in kg CO2-equivalent for the designed SOL-DAZE system was 463.2 kg CO2. Or expressed in percentage, so that generalization could take place, 16.33 %. This was the case for off-grid and hybrid cases both for SOL-DAZE and conventional PV. However, the environmental impact for the conventional on-grid case scenario could be considered null, according to the terms set for this calculation.

5. Discussion

The primary objective of the study, which was to provide MG Sustainable Engineering AB with a techno economic analysis for the SOL-DAZE project, has been successfully fulfilled. Opinion on technical feasibility and deadlines have been gathered from partners, the most relevant KPIs have been obtained, and an environmental assessment has been conducted.

Firstly, a cost analysis was conducted both for SOL-DAZE and conventional PV. This cost analysis budgeted the whole systems and gave economic values to work on.

A cost analysis comparing SOL-DAZE and conventional PV systems showed that, in the base case, all LCOEs were below Gävle's electricity price, indicating economic feasibility, especially for off-grid systems. However, SOL-DAZE presented slightly higher LCOEs than conventional PV due to higher operational costs related to software and protection. Sensitivity analyses revealed that lower sodium-ion battery prices and higher electricity prices significantly improved SOL-DAZE's competitiveness, under Spanish conditions, greater solar irradiation and energy prices increased profitability.

The Return on Investment (ROI) and Net Present Value (NPV) were positive for all scenarios, confirming overall economic viability. Adjustments in electricity price and regional conditions further enhanced the financial outcomes, especially for hybrid and on-grid configurations. The Payback Period remained below eight years in every case, representing an attractive return time.

From an environmental perspective, SOL-DAZE reduces CO_2 emissions compared to conventional PV systems and promotes circularity by enabling the reuse of up to 80 % of materials.

Furthermore, the Desolenator case demonstrates that SOL-DAZE's distributed inverter-battery architecture can support multi-energy systems such as water desalination, proving its potential for carbon-neutral utilities in remote regions.

Despite certain uncertainties, mainly cost estimations for software and the need for system oversizing in off-grid applications (17.5 % for SOL-DAZE and 25 % for conventional PV) the study highlights a major strength: the scalability of the techno-economic model, making it adaptable to systems of various sizes and contexts.

6. Conclusion

SOL-DAZE has the potential to be a technological breakthrough in the solar field. It has proven to be feasible technologically, conditions and environmentally. Economically, SOL-DAZE shows promising results. When compared to conventional PV, it can be seen how SOL-DAZE brings competitive parameters in general terms. For off-grid cases, it can be an interesting option, since the obtained LCOE is low enough to be taken into consideration and competitive with the conventional one, even more if the first sensitivity analysis is fulfilled in the upcoming years, as expected.

Sensitivity analyses show that the SOL-DAZE's optimal use currently is for places with high electricity prices, low full load hours and in a hybrid configuration for minimum economic loss, but with independence from grid in case of failure. If used in other locations, its profitability is good as well but not outstanding if compared to conventional PV. The Desolenator application confirmed that SOL-DAZE can scale from building-level systems to industrial hybrid operations, maintaining economic competitiveness and full energy autonomy.

7. References

Chiu, H.-J.et al., 2012. A Module-Integrated Isolated Solar Microinverter. *IEEE Transactions On Industrial Electronics,* 60(2), pp. 781-788.

Consultancy.eu, 2023. *Consultancy.eu.* [Online]
Available at: https://www.consultancy.eu/news/8989/report-spains-solar-power-capacity-to-see-strong-growth#:~:text=%E2%80%9CWhile%2C%20for%20example%2C%20in,between%201%2C900%20and%202%2C000%20hours.
[Accessed 2 May 2025].

Delmas, C., 2018. Sodium and Sodium-Ion Batteries: 50 Years of Research. *Advanced Energy Materials,* 8(1703137), p. 9.

Deshmukh, K. et al., 2025. Sodium-ion batteries: state-of-the-art technologies and future prospects. *Journal of Materials Science,* 60(8), pp. 3609-3633.

Dominko, R., 2025. *Kick-off meeting* [Interview] (14 April 2025).

Eléctrica, R., 2025. *Sistema Eléctrico.* [Online]

Available at: https://www.sistemaelectrico-ree.es/informe-del-sistema-electrico/mercados/precio-medio-final
[Accessed 2 May 2025].

Home Energy, B., 2025. *Baker Home Energy.* [Online]
Available at: https://bakerhomeenergy.com/blog/2016-06-14/advantages-and-disadvantages-of-microinverters-bk/
[Accessed 9 April 2025].

Kortabarria, I. & Zabala, E., 2024. *Sistemas electrónicos. Tema 4: Inversores.* Bilbao: Departamento de Tecnología Electrónica UPV/EHU.

Media, T., 2025. *Euribor rates EU.* [Online]
Available at: https://www.euribor-rates.eu/es/tipos-euribor-actualmente/4/euribor-valor-12-meses/
[Accessed 25 April 2025].

Muhammad Tawalbeh, A. A.-O. F. K. E. A. F. A. M. A., 2021. Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook. *Science of The Total Environment,* 759(143528), p. 12.

Nyholma, E., Goop, J., Odenberger, M. & Johnsson, F., 2016. Solar photovoltaic-battery systems in Swedish households - Self-consumption and self-sufficiency. *Applied Energy,* 183(1), pp. 148-159.

Pool, N., 2025. *Nord Pool.* [Online]
Available at: https://data.nordpoolgroup.com/auction/day-ahead/prices?deliveryDate=2024-04-26&currency=EUR&aggregation=MonthlyAggregate&deliveryAreas=SE3
[Accessed 25 April 2025].

SCB, 2025. *Statistical Database.* [Online]
Available at:
https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__EN__EN0301__EN0301A/SSDHalvarElHus/table/tableViewLayout1/
[Accessed 1 June 2025].

Solar, D., 2020. *Deege Solar.* [Online]
Available at: https://www.deegesolar.co.uk/string_inverters_vs_microinverters/
[Accessed 9 April 2025].

Solargis, Esmap & Group, W. B., 2016. *Global Solar Atlas.* [Online]
Available at:
http://globalsolaratlas.info/detail?c=60.660901,17.043915,11&s=60.667797,17.166824&m=site&pv=small,180,44,14.4
[Accessed 25 April 2025].

Stone, S., 2023. *Sweden's solar tax incentives in 2023: ROT and Green Deduction (grön teknik).* [Online]
Available at: https://solarstone.com/blog/swedens-solar-tax-incentives-in-2023
[Accessed 29 April 2025].

United Nations, C. C., 2015. *Process and Meetings: The Paris Agreement.* [Online]
Available at: https://unfccc.int/process-and-meetings/the-paris-agreement

Xin Lai, J. C. Q. C. X. H. L. L. H. D. Y. Z., 2023. Comprehensive assessment of carbon emissions and environmental impacts of sodium-ion batteries and lithium-ion batteries at the manufacturing stage. *Journal of Cleaner Production,* 423(138674), p. 12.