D2.5. Innovative Business Models in Distributed Generation Systems

WP2 – Green and Renewable distributed electric energy generation and storing

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November 2025

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

SMARTGYsum has been funded by the European Union's Horizon 2020 Programme under the Grant Agreement GA 955614

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Versions:

Version No.	Person in charge	Institution (acronym)	Date	Comments
1	Oleksandr Velihorskyi	CNUT	18.06.2023	First template of the deliverable report
2	Radek Kot	WUT	20.11.2025	Edits
3	Ayesha Aslam, Victor Miñambres	Senergyps	25.11.2025	Edits
4	Anas Abdullah Alvi	UEX	25.11.2025	Edits
5	Shuyu Ou, Ariya Sangwongwanich, Subham Sahoo, Frede Blaabjerg	AAU	26.11.2025	Edits
6	Luis Martínez	WUT	27.11.2025	Edits
7	Radek Kot	WUT	28.11.2025	Compilation, editorial edits, proofreading
8	Mariusz Malinowski	WUT	28.11.2025	Proofreading, approval
9	Oleksandr Velihorskyi	CNUT	08.12.2025	Proofreading, approval
10	Enrique Romero	UEX	15.12.2025	Proofreading, approval, final version

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Technical References:

Project Acronym	**SmartGYsum**
Project Title	Research and Training Network for Smart and Green Energy Systems and Business Models
Project Coordinator (PC)	Enrique Romero (eromero@unex.es) Universidad de Extremadura (UEX)
Project Duration	1 October 2021 – 31 March 2026

Deliverable No.	D2.5
Dissemination Level	Public
Work Package	WP2 – Green and Renewable distributed electric energy generation and storing
Tasks	
Lead Beneficiary	8 - WUT
Contributing beneficiary (ies)	SEPS, WUT, UEX, AAU
Data due of deliverable	30 November 2025
Actual submission date	11 December 2025

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List of abbreviations

BEN	Beneficiary
Dn	Deliverable (number)
DoA	Description of Action
DS	Doctoral School
ESR	Early Stage Researcher
ETN	European Training Network
GA	Grant Agreement
IRP	Individual Research Project
ITN	Innovative Training Network
MSn	Milestone (number)
MSCA	Marie Sklodowska-Curie Actions
PC	Project Coordinator
REC	Research Ethics Committee
RSC	Recruitment and Secondment Committee
WPn	Work Package (number)

1. Executive summary

Work Package 2 (WP2) of the SmartGYsum project focuses on advancing green and renewable distributed energy generation, storage, and intelligent control solutions that address emerging challenges in flexibility, reliability, and cost-effective integration of distributed energy resources (DERs). Within this framework, four Individual Research Projects (IRPs) have developed complementary business models that reflect the technological innovation, market potential, and socio-economic impact of next-generation decentralized energy systems. Collectively, these IRPs form a set of solutions that address strategic domains: power electronics converter technology for microgrids, smart energy management for prosumers and small businesses, virtual power plant coordination, and predictive maintenance for large-scale PV assets. Together, they outline concrete steps toward more interoperable, reliable, and cost-effective distributed generation.

IRP01 introduces an advanced hybrid inverter concept that combines a three-level T-type inverter with a two-level VSI operating in parallel. This modular architecture provides enhanced redundancy, scalability, and superior power quality performance, tailored to commercial, industrial, and microgrid applications. The IRP provides a detailed bill-of-materials (BOM) assessment, competitive positioning within European inverter markets, and pricing strategies based on component-level cost modelling. With a prototype production cost of approximately €1,888, the system is positioned competitively against market offerings in the 5–10 kW hybrid segment. The revenue model explores profitability under various pricing scenarios, highlighting strong commercial potential supported by differentiated value propositions such as fault-tolerant operation, robust monitoring, and modular design.

IRP02 expands the focus to intelligent energy management within residential and small commercial buildings. It presents a vendor-agnostic modular platform composed of two complementary components: EconoBattery, a tariff-aware optimization and storage management system, and FlexiLoad, a flexible load scheduling tool. Unlike proprietary ecosystems that restrict interoperability, the proposed solution emphasizes openness, cross-compatibility, and transparent use of publicly available market price signals. This IRP includes a comprehensive benchmark of existing commercial offerings and demonstrates a clear market gap for customizable, hardware-independent control solutions. The financial model integrates hardware sales with recurring software revenues, forming a scalable hybrid business structure. With a target market of more than one million prosumers in Poland alone, this solution addresses the ongoing regulatory shift toward dynamic pricing and net-billing, strengthening prosumer empowerment and accelerating demand-side flexibility.

IRP03 addresses the coordination of distributed assets at the system level through the concept of a Virtual Power Plant for Cost Efficiency (VPPEC). The IRP proposes a software-centric platform enabling DER aggregation, market participation, and provision of ancillary services. Its business model builds upon a subscription-based structure reinforced by additional revenue streams from energy arbitrage, capacity markets, and service compensation. A detailed techno-economic analysis, including revenue, OPEX, EBITDA, and cash-flow projections, demonstrates strong financial viability with a payback period of approximately 1.5 years. The IRP highlights significant value in combining AI-based forecasting, real-time optimization, and user-friendly interface design to deliver up to 66% cost reductions for participating users under specific operating modes. The platform targets a wide range of stakeholders including prosumers, DSOs, aggregators, and commercial customers, showcasing broad applicability across evolving smart-grid environments.

IRP04 focuses on large-scale PV installations and introduces an innovative performance-driven predictive maintenance framework. Instead of traditional subscription pricing, the model adopts a risk-sharing approach in which service providers are compensated proportionally to verifiable reductions in downtime and maintenance costs. This aligns incentives, removes upfront investment barriers, and encourages continuous diagnostic improvements. The IRP integrates edge-based analytics, advanced condition-monitoring algorithms, and secure data-handling practices, enhancing reliability while minimizing cybersecurity risk. A structured assessment of operational workflows—from data acquisition to maintenance recommendation—demonstrates the practical feasibility of this

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approach. The model also includes a detailed risk analysis with mitigation strategies addressing technical, operational, and regulatory uncertainties. As predictive maintenance markets rapidly expand, this IRP positions itself as a next-generation service offering for improving PV fleet performance.

Across all four IRPs, several unifying themes emerge:

- Interoperability and openness: IRP02 and IRP03 both prioritize vendor-agnostic, flexible architectures that enable cross-platform integration.
- Data-driven intelligence: IRP03 and IRP04 leverage advanced forecasting, optimization, and diagnostic algorithms to enhance economic and operational performance.
- Component-level techno-economics: IRP01 provides a rigorous BOM-based costing approach that strengthens commercial realism in product design.
- Value creation through digitalization: All IRPs embed digital tools—from cloud platforms to edge-computing—that reduce operational costs and improve resilience of distributed systems.

Together, these IRPs demonstrate how WP2 contributes to the broader goals of SmartGYsum by developing innovative, market-ready solutions that support greener, more resilient energy systems. The portfolio spans the entire value chain—from hardware development to system-level coordination and lifecycle asset management—reflecting the multidimensional nature of future distributed generation ecosystems.

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2. IRP01 – Cooperative Smart Inverters for Green Generation Plants

2.1. Introduction

This report presents the business model for a hybrid parallel inverter system designed for commercial, industrial, and microgrid applications. The system utilizes a modular architecture combining a three-level (3L) T-type inverter and a two-level (2L) voltage source inverter (VSI) operating in parallel. This combination offers enhanced flexibility, fault tolerance, and superior power quality for modern distributed energy resources.

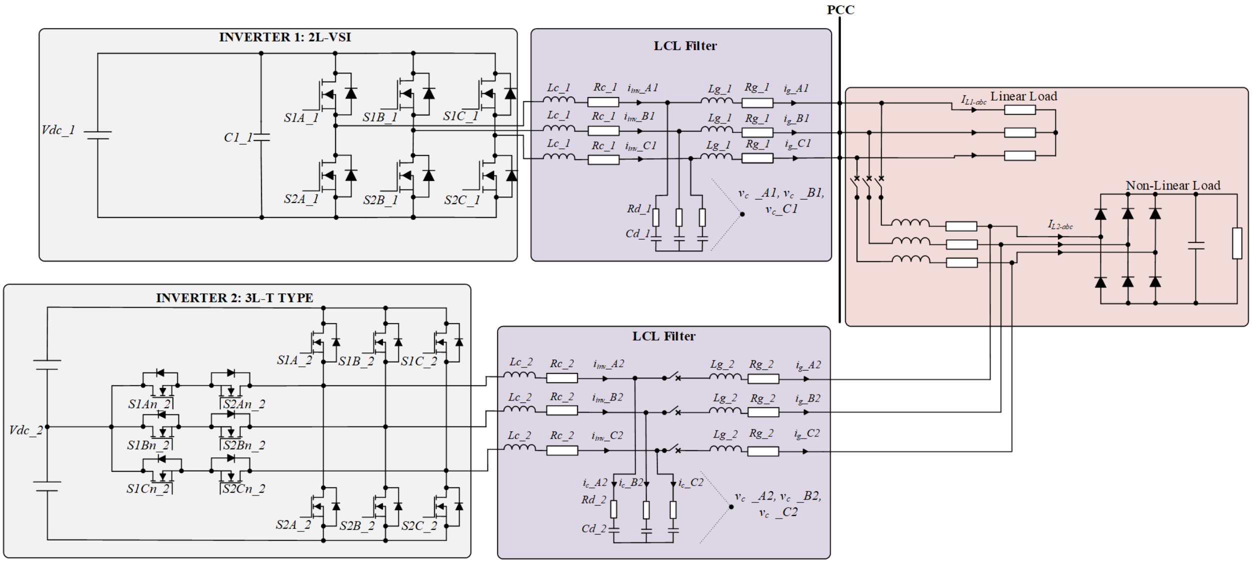

Figure 1 Schematic diagram of the AC nanogrid with parallel hybrid inverter system.

The model integrates detailed BOM costing, competitive pricing benchmarks from European markets, and comprehensive revenue modeling, providing a clear pathway for scalable commercialization with strong profit potential.

2.2. Project Overview

Product Architecture:

The inverter platform consists of two main units in parallel operation:

- 3L T-type inverter board: Provides high-efficiency three-level power conversion with enhanced voltage handling and reduced harmonic distortion.
- 2L VSI board: Offers a simpler two-level topology, enabling compatibility, cost-efficiency, and redundancy support in the parallel configuration.
- Measurement and Modulation Boards: Separate modules for accurate sensing, signal conditioning, protection, and modulation logic to enable robust and fault tolerant operation.

Target Market:

- Commercial and Industrial Microgrid operators
- Distributed Energy Resource aggregators
- Remote/off-grid installations in critical infrastructure (healthcare, education)
- Energy-as-a-service providers focusing on hybrid power solutions

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2.3. Market Analysis and Benchmarking

Recent European market studies show that competitive inverter prices for the 5–10 kW three-phase hybrid segment range from approximately €1,700 to €3,100 per unit depending on features and warranties. Leading providers include Deye, Sungrow, ABB/Fimer, Growatt, and Solplanet. Our prototype's combined BOM cost for both 3L T-type and 2L VSI units totals approximately €1,888, positioning it competitively within this range. This dual topology gives our system a technological edge through improved fault tolerance and load sharing being the key differentiators in grid-interactive microgrid applications.

Table 1 Market Pricing and Features Comparison for 5–10kW Three-Phase Hybrid Inverters (Europe, 2025).

Brand	**Model**	**Price Range (€)**	**Phase Type**	**Communication/Protection**	**Notable Features**
Deye	SUN-5K-SG04LP3-EU	1,900–2,200	3-phase	RS485, WiFi, surge protection	Full hybrid, EU compliant
Sungrow	SH10RT	2,300–2,900	3-phase	RS485, Ethernet, Type II SPD	High efficiency, warranty options
Solis	3P10K-4G	1,800–2,300	3-phase	WiFi, DC/AC Type II SPD	Easy monitoring
ABB/Fimer	UNO-DM-10.0-TL-PLUS-B	2,400–3,100	3-phase	RS485, Ethernet, integrated protection	Robust, industry recognised
Solplanet	ASW 6000H-S	1,500–2,100	3-phase	WiFi, surge protection	Reliable entry-level
Growatt	MIC 6000TL-X	1,600–2,250	3-phase	WiFi, DC protection	Compact, affordable

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2.4. Business Model Canvas

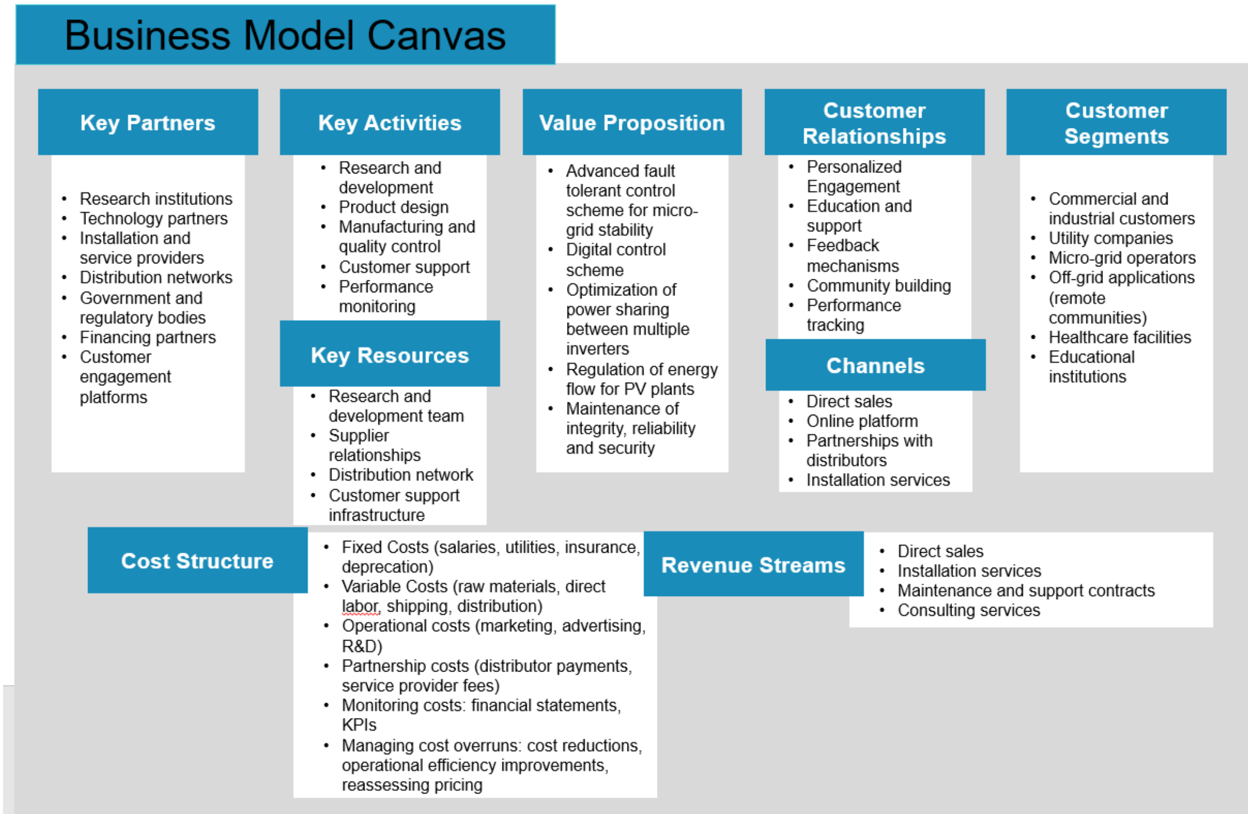

Figure 2 Business model canvas of the proposed system.

Key Partners:
Our primary partners include research institutions and technology providers who help develop and refine our advanced inverter control solutions. Reliable component suppliers ensure consistent access to high-quality MOSFETs, sensors, and PCBs. Certified installation and service providers enable proper deployment and maintenance on-site. Distribution partners expand sales reach across Europe. We also collaborate with government bodies for certification and regulatory compliance, while financing partners support flexible purchasing models. Lastly, customer engagement platforms facilitate ongoing feedback and community building.
Key Activities:
We conduct research and development to optimize parallel control algorithms and power electronics design. Product design and prototyping ensure manufacturability and compliance with grid codes. Manufacturing activities focus on maintaining quality and scale production. Customer support and service including training, performance monitoring, and remote diagnostics form vital ongoing functions.
Key Resources:
Our core resources include an expert R&D team experienced in inverter topology and control; strong supplier relationships securing high-quality components; robust manufacturing and testing infrastructure; and digital platforms supporting customer service and performance analytics.
Value Proposition:
We offer a modular parallel inverter combining a three-level T-type and two-level VSI for enhanced reliability, scalability, and power sharing capability. Advanced control schemes maintain grid stability with fault tolerance. Modular measurement and modulation boards facilitate maintenance and upgrades, lowering downtime. Our digital monitoring improves performance visibility and predictive maintenance.
Customer Relationships:
We foster personalized engagement through comprehensive training and support services, ensuring customer empowerment. Feedback mechanisms and community networks strengthen relationships and inform continuous product improvement. Proactive performance tracking and maintenance programs build trust and satisfaction.
Channels:

Sales channels include direct enterprise outreach to microgrid developers and industrial customers, supported by regional distributors. Certified installer networks deliver compliant onsite deployment. An online platform provides technical resources and customer service.

Customer Segments:

Target customers include commercial and industrial microgrid operators, utilities piloting distributed energy resources, off-grid critical infrastructure, and educational or healthcare institutions requiring resilient renewable energy solutions.

Cost Structure:

Key costs include fixed expenses such as salaries, R&D, certifications, and utility charges. Variable costs encompass component procurement, assembly, shipping, and distribution fees. Operational expenses for marketing, customer support, and partnership management are also significant.

Revenue Streams:

Primary revenues derive from hardware sales. Additional income comes from installation and commissioning services, recurring maintenance and support contracts, and consulting for customized system integration.

2.5. Pricing and BOM Costing

Using detailed supplier data, the bill of materials encompasses component pricing for both inverter types and auxiliary boards, including:

- MOSFETs, gate drivers, amplifiers, sensors for each board
- PCB fabrication costs (2-layer and 4-layer variants)
- Passive components (capacitors, resistors, inductors), connectors, wiring, enclosure.

Pricing scales are modeled at unit quantities of 1, 5, 10, 25, 50, and 100, reflecting volume discounts. This tiered costing provides transparency on economies of scale and informs pricing strategies and cost reductions through supplier negotiation and alternate sourcing.

Table 2 Production Cost Estimates and Unit Cost Variation of 2L VSI by Manufacturing Volume.

Component	Price per unit at 1pc (€)	Price per unit at 5pc (€)	Price per unit at 10pc (€)
3-phase 2L VSI prototype (Taraz technologies)	688	3440	6880
USM-3IV Isolated voltage current sensor (Taraz technologies)	600	3000	6000
Taraz shipping and tax estimate	73	73	73
LCL Filter inductors (6 units)	360	342	331.2
LCL Filter capacitors (3 units)	105	100.8	97.65
Cables, connectors, wiring (per meter)	4.5	4.41	4.32
Cables, connectors, wiring total (15-20 meters)	78.75	77.17	75.6
Mounting/enclosure	100	97	95

Table 2.1 Production Cost Estimates and Unit Cost Variation of 2L VSI by Manufacturing Volume.

Component	25pc (€)	50pc (€)	100pc (€)	Quantity	Total cost at 1pc (€)
3-phase 2L VSI prototype (Taraz technologies)	17200	34400	68800	1	688
USM-3IV Isolated voltage current sensor (Taraz technologies)	15000	30000	60000	1	600
Taraz shipping and tax estimate	73	73	73	1	73
LCL Filter inductors (6 units)	316.8	306	288	6	2160
LCL Filter capacitors (3 units)	93.45	91.35	87.15	3	315
Cables, connectors, wiring (per meter)	4.23	4.09	3.96	1	4.5
Cables, connectors, wiring total (15-20 meters)	74.03	71.58	69.3	1	78.75
Mounting/enclosure	92	90	87	1	100

Table 3 Production Cost Estimates and Unit Cost Variation of 3L T-type (Power Board) by Manufacturing Volume.

Component	Price per unit at 1pc (€)	Price per unit at 5pc (€)	Price per unit at 10pc (€)
MOSFET switches	10.5	9.5	9.1
Gate Drivers	3.6	3.2	3
Isolation Amplifiers	5.2	4.8	4.5
Operational Amplifiers	4.5	4.3	4.1
Inductors	1.6	1.5	1.4
Resistors/Capacitors (Bulk Average)	0.25	0.22	0.2
Connectors/Headers	1.1	1	0.9
PCB Fabrication (4-layer)	90	85	80

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Table 3.1 Production Cost Estimates and Unit Cost Variation of 3L T-type (Pobwer Board) by Manufacturing Volume.

Component	25pc (€)	50pc (€)	100pc (€)	Quantity	Total cost at 1pc (€)
MOSFET switches	8.5	8	7.5	14	147
Gate Drivers	2.8	2.5	2.3	14	50.4
Isolation Amplifiers	4.1	3.9	3.7	6	31.2
Operational Amplifiers	3.9	3.7	3.5	3	13.5
Inductors	1.3	1.2	1.1	20	32
Resistors/Capacitors (Bulk Average)	0.18	0.15	0.12	250	62.5
Connectors/Headers	0.8	0.75	0.7	15	16.5
PCB Fabrication (4-layer)	75	70	65	1	90

Table 4 Production Cost Estimates and Unit Cost Variation of 3L T-type (Measurement Board) by Manufacturing Volume.

Component	Price per unit at 1pc (€)	Price per unit at 5pc (€)	Price per unit at 10pc (€)
LA55-P Current Sensor	14.5	13.8	13
LV-25-P Voltage Sensor	13	12.2	11.5
Resistors (Bulk Average)	0.3	0.28	0.26
Capacitors (Bulk Average)	0.35	0.33	0.31
Operational Amplifiers	5	4.7	4.5
Connectors/Headers	1.2	1.08	1
PCB Fabrication (2-layer)	50	47	45

Table 4.1 Production Cost Estimates and Unit Cost Variation of 3L T-type (Measurement Board) by Manufacturing Volume.

Component	25pc (€)	50pc (€)	100pc (€)	Quantity	Total cost at 1pc (€)
LA55-P Current Sensor	12.3	11.7	11.3	7	101.5
LV-25-P Voltage Sensor	10.8	10.3	9.8	7	91
Resistors (Bulk Average)	0.25	0.23	0.2	30	9
Capacitors (Bulk Average)	0.28	0.26	0.23	30	10.5
Operational Amplifiers	4.2	3.9	3.8	5	25
Connectors/Headers	0.9	0.86	0.8	10	12
PCB Fabrication (2-layer)	42	40	36	1	50

Table 5 Production Cost Estimates and Unit Cost Variation of 3L T-type (Modulation Board) by Manufacturing Volume.

Component	**Price per unit at 1pc (€)**	**Price per unit at 5pc (€)**	**Price per unit at 10pc (€)**
Logic gate IC (SN74LS32DG4)	1.5	1.4	1.35
Logic gate IC (SN74HCS08QDRQ1)	1.8	1.7	1.6
Voltage Regulator (LD1117V50)	1	0.95	0.9
Diodes (Zener MMSZ5251B-7-F)	0.2	0.18	0.16
Capacitors (Bulk Average)	0.35	0.33	0.31
Resistors (Bulk Average)	0.3	0.28	0.27

Connectors	1	0.9	0.85
PCB Fabrication (2-layer)	40	38	36

Table 5.1 Production Cost Estimates and Unit Cost Variation of 3L T-type (Modulation Board) by Manufacturing Volume.

Component	25pc (€)	50pc (€)	100pc (€)	Quantity	Total cost at 1pc (€)
Logic gate IC (SN74LS32DG4)	1.3	1.25	1.2	3	4.5
Logic gate IC (SN74HCS08QDRQ1)	1.5	1.4	1.3	5	9
Voltage Regulator (LD1117V50)	0.85	0.8	0.75	1	1
Diodes (Zener MMSZ5251B-7-F)	0.14	0.13	0.12	3	0.6
Capacitors (Bulk Average)	0.29	0.28	0.25	60	21
Resistors (Bulk Average)	0.25	0.23	0.2	80	24
Connectors	0.8	0.75	0.7	6	6
PCB Fabrication (2-layer)	35	33	30	1	40

2.6. Revenue Modeling

- Revenue models compute profit margins and sales volume targets conditioned on varying selling prices informed from market benchmarks:
- Base production cost (combined 3L T-type + 2L VSI) estimated at approx. €1,888 per unit for prototype-scale.
- Target price range from €2,000 to €3,100 to remain competitive but profitable.
- Profit per unit calculated as selling price minus production cost; units required to meet set revenue targets (e.g., €10k, €25k...) are derived accordingly.

Total system prototype production cost

- 2L VSI inverter: ~€688 per unit
- 3L T-type inverter: ~€1,200 per unit

Total system prototype production cost = €688 + €1,200 = €1,888
Revenue Calculation Table
Assumption: Production cost is €1,888 per inverter system

Table 6 Revenue and Units-to-Sell Projections at Various Selling Prices and Revenue Targets.

Revenue Target (€)	Selling Price (€)	Profit/Unit (€)	Units to Sell for Revenue Target
10,000	2,000	112	90
10,000	2,500	612	17
10,000	3,100	1,212	9
25,000	2,000	112	223
25,000	2,500	612	41

Revenue Target (€)	Selling Price (€)	Profit/Unit (€)	Units to Sell for Revenue Target
25,000	3,100	1,212	21
50,000	2,000	112	446
50,000	2,500	612	82
50,000	3,100	1,212	41
100,000	2,000	112	893
100,000	2,500	612	164
100,000	3,100	1,212	83

where:

Profit/Unit = Selling Price – Production Cost (€1,888).

Units to Sell = Revenue Target / Profit per Unit

- Production cost of €1,888 includes the full combined inverter system with both 2L VSI and 3L T-type inverters based on detailed BOM pricing and supplier quotes.
- Selling prices are chosen based on 2025 European market inverter prices between €2,000 and €3,100.
- Revenue targets vary (10k, 25k, 50k, 100k) to explore different business scale scenarios.

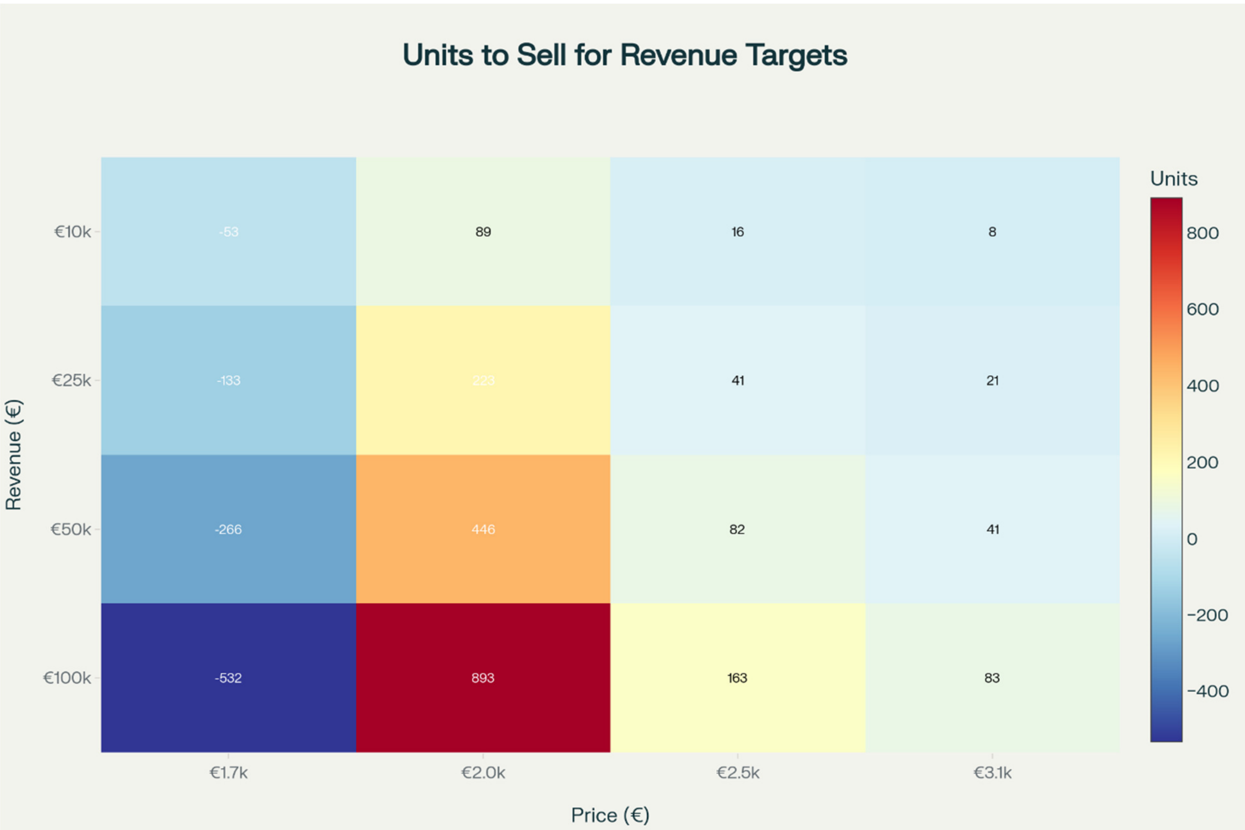

Figure 3 Units to Sell by Price & Revenue for Complete Inverter System (€1,888 Cost).

- Each cell shows the units to sell for its specific revenue target and selling price.
- Selling at higher prices greatly reduces the number of units needed to reach the same revenue.

- Results are calculated as: Units = Revenue Target / (Selling Price - Production Cost).

2.7. Business Model Pitch

Our hybrid parallel inverter system offers a uniquely balanced solution powered by the hybrid operation of advanced three-level T-type and reliable two-level VSI topologies. The combined inverter unit harnesses the strengths of both technologies, achieving superior power quality, fault resilience, and scalable capacity. Distributed energy resources and microgrids face increasing complexity due to variable renewable inputs and critical reliability needs; our solution mitigates these challenges with intelligent load sharing and real-time diagnostics enabled by modular measurement and modulation boards.

The product targets microgrid operators, utilities, and off-grid infrastructures demanding stability and modular reliability. Partnering with installers and leveraging a robust distribution network allows effective outreach. Comprehensive after-sales service, proactive maintenance, and data-driven performance monitoring secure long-term customer engagement and satisfaction.

Financially, the product is positioned within established European price points but enhanced with differentiated service contracts and performance guarantees to ensure sustainable profitability. The detailed cost model grounded in actual BOM pricing and scalable manufacturing practices underpins accurate margin forecasting and business scalability. Our go-to-market approach emphasizes pilot site validation, iterative product improvement, and strategic financing partnerships to accelerate adoption.

Compared to existing inverter business models that focus mainly on tariff structures or financing schemes, this work introduces a component-level, BOM-driven techno-economic framework tailored to hybrid AC nanogrids with parallel inverter topologies.

3. IRP02 – Development of Power Generators for Smart Buildings with Advanced Power Sharing Capabilities

3.1. Introduction

The present deliverable provides a report about the developed business model related to the Development of power generators for Smart Buildings with Advanced Shared Capabilities. The proposal consists in amodular platform for prosumers and small businesses and is described by two core modules. EconoBattery integrates a battery pack, bidirectional converter and optimization software to control charge and discharge in real time, while FlexiLoad schedules flexible appliances (EV charging, heating, dish-washer, etc.) so that the over all energy can be managed with the objective of electricity bills. Unlike many current offers that are tightly coupled to a single hardware vendor or depend on exclusive partnerships with specific aggregators, these devices are designed to provide cross-compatibility with other devices. Different to other solutions that expose only limited control, the proposed solution is vendor-agnostic and open-source, using publicly available spot and day-ahead price signals instead of proprietary tariffs. The diagram of the proposed product is shown in

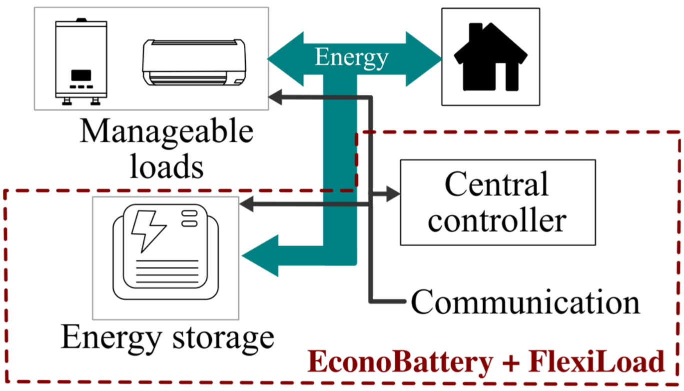

Figure 2.Diagram of the product for the business model

3.2. Objectives of the business model

- Enable residential prosumers and small businesses to reduce their electricity bills and increase self-consumption by intelligently coordinating storage (EconoBattery) and flexible loads (FlexiLoad).
- Provide a vendor-agnostic, open-source platform that avoids lock-in to specific hardware or suppliers and supports rapid development of new applications, tariffs, and research experiments.
- Create sustainable, scalable revenues by combining upfront hardware sales with recurring software and service income, including integrations with aggregators, retailers, and technology partners.
- Build a flexibility-ready asset base that aggregators and energy service companies can use for demand response and grid services, leveraging transparent, public price signals rather than exclusive bilateral agreements.

3.3. Project Overview

Product description

The platform consists of two parts that can be acquired together or separately. The first one is a bundle consisting of a battery and its corresponding power converter, together with decision-making software that determines the optimal operating condition of the battery to minimize the electricity bill and satisfy operational constraints. This system will be referred to as EconoBattery. The second part of the platform, named FlexiLoad, is a load management system that schedules appliances to contribute to the electricity bill minimization target, provided that the user makes them available for this purpose. A detailed description of the two modules is provided in Table I.

Table I. Detailed product description of EconoBattery and FlexiLoad modules.

Module	Software	Hardware
EconoBattery	- Real-time tariff-aware optimization: - Constraint-aware operation: respects user comfort, power limits, grid constraints and contractual limits automatically. - Cloud connectivity & analytics: remote monitoring, dashboards, and history. - Open-source code: allows for third party improvements and close collaboration with academia.	Modular battery pack: scalable capacity for different customer segments (home, small business). - Bidirectional power converter – high-efficiency inverter/charger that supports grid-tie, and islanded modes. - Advanced metering interfaces: integration with smart meters/CT clamps for accurate consumption and export measurement. - Communications gateway: built-in connectivity.
FlexiLoad	- Automated appliance scheduling: optimally shifts loads within user-defined availability windows. - User preference engine: configurable comfort and priority settings so automation is acceptable and low-friction for end-users.	- Retrofit control of existing appliances: lowering adoption barriers and upfront cost. - Embedded metering in devices: per-appliance measurement for granular optimization.

	- Dynamic price response: adapts appliance operation to real-time prices.	- Private data: statistics are only accessible to the end user. - Interoperable interfaces – support for standard protocols (e.g., Modbus) to integrate diverse assets.

Justification and added value.

Existing battery optimization solutions often depend on exclusive partnerships between hardware vendors and specific aggregators or retailers. For example, the tight integration of Tesla Powerwall with Octopus Energy's Kraken platform and smart tariffs in the UK and Spain, as well as the collaboration between Enphase and Frank Energie in the Netherlands [1, 2].
Although third-party open-source solutions are available, they do not enable direct control of the battery system, but rather interaction with vendor-specific software [3].
At the same time, many third-party and even open-source solutions only expose limited communication interfaces and do not allow direct, continuous control of the battery management, restricting truly optimal operation. In contrast, the proposed EconoBattery + FlexiLoad platform is vendor-free and open-source, designed to interface with various storage and load technologies while providing full control over charge/discharge and flexible loads.

The initial target market comprises residential prosumers in detached houses and small commercial customers who already operate rooftop photovoltaic (PV) systems in Poland, under any pricing scheme. This is possible thanks to the open availability of day-ahead and spot market prices in Poland [4], which is crucial for the optimization engine. Compared to other solutions, this approach removes the need for commercial agreements between equipment vendors and electricity suppliers.

3.4. Market Analysis and Benchmarking

At the end of 2024, there were approximately 1.5 million renewable photovoltaic micro-installations in Poland, with a total capacity of around 12.7 GW, and 98% of these were primarily residential [5]. Moreover, there is a regultaroy shift from old net-metering to net-billing, meaning that new prosumers sell surplus energy at the market price, which increases the interest in electricity bill minimization solutions that account for different price ratings. The existing solutions are tightly integrated ecosystems where software is proprietary and tied to specific hardware. A comparison of products available in the market related to battery units and load management is described in Table II and Table III, respectively.

Table II. Available products related to battery installation.

Brand	**Model / Platform**	**Price range for 10 kWh battery (€)**	**Features**
Tesla	Powerwall 2 / 3	6,000–8,500	• Time-based control and TOU optimization via Tesla app.Tesla ecosystem. • Deep integration with selected agregattors.
sonnen	sonnenBatterie Evo	6,000–8,000	• Energy manager with self-learning charge/discharge algorithm. • Closed ecosystem with proprietary cloud software
Huawei	LUNA2000	3,400-4,000	• Modular battery •Tight integration with Huawei inverters and FusionSolar cloud platform
BYD	Battery-Box	~3,700	• Paired with 3rd-party hybrid inverters (Fronius, SMA, etc.), where the inverter performs the energy management. • Monitoring interfaces exist via compatible inverters.

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Table III. Available products related to load management.

Brand	Product / Service	Price (€)	Features
Fronius	Ohmpilot	~800	• Optimizes self-consumption rather than explicit market price.
Tibber	Tibber app + dynamic electricity tariff & smart charging	Dynamic supply contract with monthly base fee around €5.99	• Shifts EV charging and electric heating to cheap, green hours.
Homey / LG	Homey Pro	~350	• Integrates a wide range of devices via Zigbee • Whole-home consumption, solar generation tracking. • Very flexible ecosystem, but requires user configuration

3.5. Business Canvas

The business canvas of the proposal is summarized in ¡Error! No se encuentra el origen de la referencia..

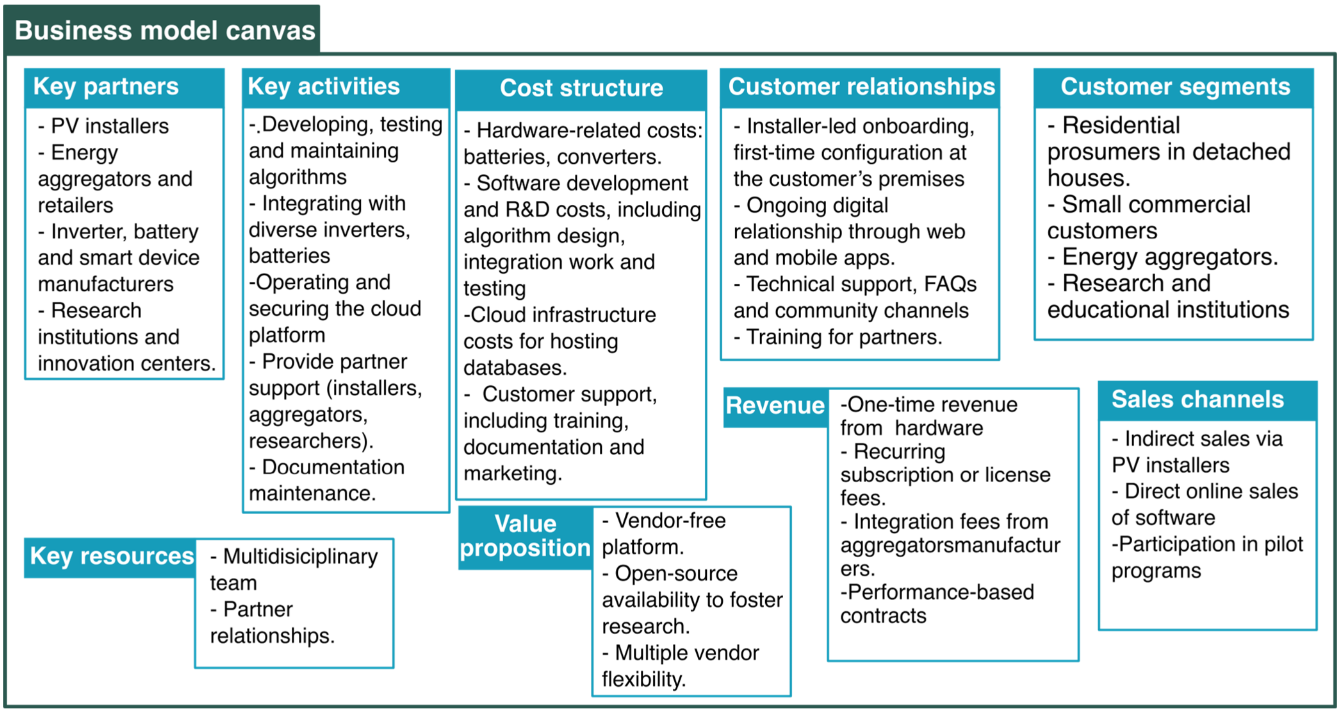

Figure 3. Business model canvas of the proposal.

Key partners:
PV installers and companies that provide access to end customers and handle on-site integration, while energy aggregators and retailers use EconoBattery + FlexiLoad as a flexibility asset. Power electronics converter manufacturers can include EconoBattery software in their own devices.
Key activities:
Maintenance and development of optimization algorithms and an open-source platform. Customer support and service to ensure up-to-date monitoring and functionality of the interface between the pricing information platform.
Key resources:
Multidisciplinary team that, among other tasks, is in charge of: development of novel algorithms, communication software at the edge level, and cloud-based interfacing maintenance, development of competitive power converter proposals.
Value proposition:
A vendor-free, open-source platform that gives complete, real-time control of batteries and flexible loads, enabling advanced research, innovative tariffs, and new applications without lock-in or exclusive partnership.
Customer relationships:

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Created through installer onboarding, self-service web or app interfaces, and ongoing digital support with transparency on savings and performance.

Sales Channels:

Primary customers are residential prosumers in detached houses and small businesses with existing PV installations

Customer segments:

Residential prosumers in detached houses and small businesses, which may or may not have a photovoltaic system. The concept of payback time is the driving factor. PV installers and energy aggregators that will include the product into their existing offers.

Cost structure:

Significant costs arise from hardware components and manufacturing, cloud infrastructure, R&D and software development, technical support, and partner acquisition and training.

Revenue streams:

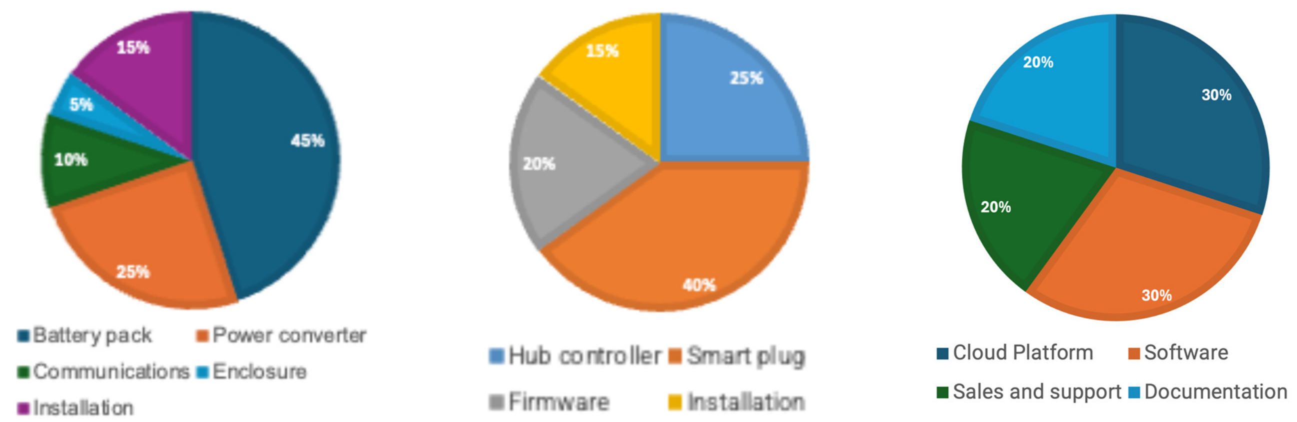
Revenues are generated from the sales of EconoBattery hardware, a single payment for one year of software without support, and subscription-based fees for enhanced optimization algorithms and continuous support.

3.6. Economic and Financial Plan

In order to analyse the profitability and the financial structure of the project, it is necessary to describe the information on the cost breakdown and revenue plan, which together will determine the cash flow and balance of the proposal.

Cost Breakdown

The suggested cost structure is organized into three sections. Two sections correspond to the costs related to the core products, EconoBattery and FlexiLoad, and the remaining section corresponds to shared costs for both products. The percentages of each concept to the respective cost section are summarized in Figure 4(a), Figure 4(b), and Figure 4(c), for the EconoBattery bundle, the FlexLoad including four smart plugs, and the shared costs, respectively.



(a) (b) (c)

Figure 4. Cost breakdown of the proposal. (a)EconoBattery. (b) FlexiLoad. (c) Shared costs.

Pricing scheme

The pricing scheme and revenue model consider three sales cases. One is for only selling the EconoBattery device and software, the second is for only delivering the FlexiLoad module, and lastly, a bundle offer in which both products can be purchased. Indicative prices for each case are summarized in Table IV.

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Table IV. Pricing scheme for three different cases.

Product	Unit cost (€)	Selling price (€)	Recurring software fee (€ / month)	Notes
EconoBattery	4000	5500	12 (EconoBattery Optimization)	10 kWh battery + converter + commissioning + Year 1 SW included, subscription starts in Year 2.
FlexiLoad	400	700 (gateway + 4 controllers)	8 (FlexiLoad Scheduling & App)	Can be sold as independent add on.
Bundle: EconoBattery + FlexiLoad	4300	5950 (combined hardware, discounted)	15 (Combined EconoBattery + FlexiLoad SW)	Bundle discount and single subscription covers both modules.

Revenue plan.

From the pricing scheme, it can be noted that the revenue streams come from the following:

1. Hardware Sales (Upfront)
- EconoBattery hardware revenue per standalone customer: €5500.
- FlexiLoad hardware revenue per standalone customer: €700.
- Bundle hardware revenue per customer: €5950.

2. Recurring Software / SaaS Revenue
- EconoBattery-only customer: €12 / month (€144 / year).
- FlexiLoad-only customer: €8 / month (€96 / year).
- Bundle customer: €15 / month (180 € / year) covering both modules.
- With an average customer lifetime of 8–10 years, the revenue can reach € 1400–€ 1800.

Cash Flow

The expected sales for the first four years and the corresponding cash inflow and outflow are summarized in Table V. It can be noted that despite the differences in profit margin for each product the expected overall profit for sales of the three options is approximately 40% without considering the license fees, or additional revenues obtained from partnering with suppliers.

Table V. Cash flow

Year	Sold units			Cash (€)	
	EconoBattery	**FlexiLoad**	**Bundle**	**Outflow**	**Inflow**
1	40	80	30	321000	454500
2	50	150	40	432000	618000
3	60	350	50	595000	872500
4	60	300	50	575000	837500

3.7. Business Pitch

We offer a pair of smart energy helpers for homes and small businesses that may already have solar panels, but feel they are not getting the full benefit. EconoBattery stores extra solar energy in a battery and decides when to charge and when to use it, so that you rely less on expensive electricity from the grid. FlexiLoad considers the appliances you choose to connect, such as water heaters, car chargers, or other plug-in devices, and adjusts their use to times when electricity from the grid is cheaper, without compromising your comfort. Together, they work in the background so that more of the energy you produce stays with you.

The product is aimed at detached houses and owners of small businesses who already have solar panels and want lower bills, more independence, and better use of their own clean energy. We work closely with local solar installers and energy service companies, who can offer the system as part of new installations or as an upgrade to existing ones, making it easy for customers to get a complete solution from a trusted local partner. Clear guidance, simple mobile and web access, and friendly support help customers understand what is happening and stay in control at all times. The offer combines a one-time purchase of the battery and control devices with a modest monthly service fee that keeps the software up to date and the cloud service running. Prices are designed to fit within the usual range of European home battery and smart home systems, while giving customers extra value by coordinating both storage and appliances in one place.

Compared to many existing solutions that lock you into a single brand, depend on special deals with one electricity retailer, or hide their decision-making behind complex settings, this business model puts openness and flexibility first. The system is designed to work with different brands of batteries and devices, it uses publicly available information about electricity prices, and it gives clear, direct control over how the battery and connected appliances behave. This creates a simple way for customers to share the benefits of utilizing smarter solar energy.

3.8. References

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4. IRP03 – Virtual Power Plant for operation, both isolated and connected

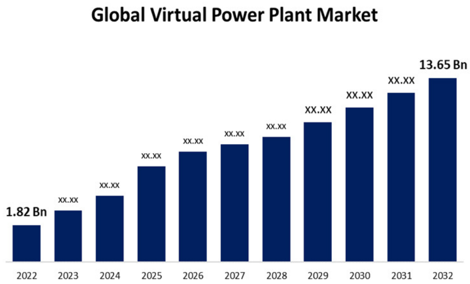
4.1. Introduction

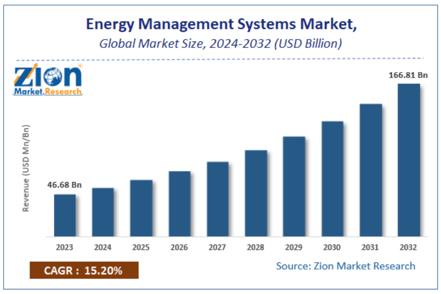
The name of the application is chosen as VPPEC (Virtual Power Plant for Cost Efficiency) in which the motto is chosen as "Providing Economican Energy for All". Some of the main features of the application are given below:

- Price Minimization of up to 15%
- Price Minimization of up to 44.1% (Peak Shaving Constraint)
- Price Minimization of up to 66.92% (Providing Ancillary Services)
- User friendly interface
- Personalized services
- Eco-Friendly Solution
- Social Awareness

4.2. Market and Impact on Society

VPPs enable market participation for smaller producers, offering ancillary services, peak shaving, demand response, and grid stabilization. In diversified markets, VPPs improve resilience, flexibility, and cost efficiency by dynamically coordinating varied resources. The current VPP Market is USD 48 Million in Spain and USD 1951.2 million globally in which the main customers are commercial VPP users, DSOs and aggregators. The current EMS Market is USD 143.1 Million in Spain and USD 57.33 Billion globally mostly for the EMS Users.





Global VPP and EMS Market

The main business plan is based on the following:

- Subscription model: 15 Euro/Month
- To collaborate with industries for reducing price and take a percentage of the reduction in exchange
- 1st year forecast: 500 Customers with a Net profit of €758K
- 2nd year forecast: 650 Customers with a Net profit of €1.6M
- 3rd year forecast: 800 Customers with a Net profit of €2.5M
- Providing ancillary services as well as capacity.

4.3. Financial Model Analysis

Technical		Market	
Parameter	Value	Parameter	Value
Total aggregated capacity	20 MW	Energy selling price (average)	€60/MWh (Spain)
Battery storage capacity	12 MWh	Ancillary services revenue	€35/MWh
PV generation	20,000 MWh/year	Capacity market price	€60/kW-year
Customers aggregated	800 prosumers by Year 3	VPP platform fee per user	€15/month

Cost Inputs		Financial	
Cost Item	Value	Parameter	Value
Capex (control hardware, metering, servers)	€1,000,000	Discount rate	10%

Software platform license	€200,000/year	Inflation	N/A
O&M + staff	€250,000/year	Tax rate	21%
IT cloud + communication	€100,000/year		
Customer acquisition cost	€300/prosumer		

Year	DER Availability	Effective Capacity
Year 1	50%	10 MW
Year 2	75%	15 MW
Year 3	100%	20 MW

Total VPP revenue comes from several streams:

A. Energy Market Arbitrage Revenue

R_{energy}=MWh_{sold} × Price

Assume VPP dispatches 7,000 MWh/year in year 1, 10,000 MWh/year in year 2 and 14,000 MWh/year in year 3 keeping the price constant:

Year 1: R_{energy}=7,000×60=€420,000

Year 2: R_{energy}=10,000 ×60=€600,000

Year 3: R_{energy}=14,000 ×60=€840,000

B. Ancillary Services Revenue

Frequency regulation, reserve, ramping:

R_{anc}= $Capacity_{MW}$ × Hours × Price

Assume 10 MW in year 1, 15MW in year 2 and 20MW in year 3 participating 3000 h/year:

Year 1: R_{anc}=10×3000×35/1000 = €1,050,000

Year 2: R_{anc}=15×3000×35/1000 = €1,575,000

Year 3: R_{anc}=20×3000×35/1000 = €2,100,000

C. Capacity Market Revenue

R_{cap}=$Capacity_{kW}$ × Price

Year 1 for 10kW: R_{cap}=10,000×60=€600,000

Year 2 for 15kW: R_{cap}=10,000×60=€900,000

Year 3 for 20kW: R_{cap}=10,000×60=€1,200,000

D. VPP Platform Subscription Fees

R_{sub} = N_{users} × Fee ×12

Year 1 for 500 prosumers: R_{sub} = 500×15×12 = €90,000

Year 2 for 650 prosumers: R_{sub} = 650×15×12 = €117,000

Year 3 for 800 prosumers: R_{sub} = 800×15×12 = €144,000

Total Annual Revenue

Year 1: R_{total}=420000+1050000+600000+90000 = €2,160,000

Year 2: R_{total}=600000+1575000+900000+117000 = €3,192,000

Year 3: R_{total}=840000+2100000+1200000+144000 = €4,284,000

Annual Operating Costs

Fixed OPEX

- Software license: €200,000
- O&M and personnel: €250,000

- IT cloud + comms: €100,000

Variable OPEX

Customer Acquisition Cost C AC:
Year 1: 500 × €300 = €150,000
Year 2: 150 × €300 = €45,000
Year 3: 150 × €300 = €45,000

Total Annual OPEX

Year 1: OPEX=200000+250000+100000+150000=€700,000
Year 2: OPEX=200000+250000+100000+45,000=€650,000
Year 3: OPEX=200000+250000+100000+45,000=€650,000

EBITDA

EBITDA = Revenue−OPEX

Year	Revenue (€)	OPEX (€)	EBITDA (€)
Year 1	2,160,000	700,000	1,460,000
Year 2	3,192,000	650,000	2,542,000
Year 3	4,284,000	650,000	3,634,000

Depreciation

Assuming 5-year straight-line with a CAPEX of €2,500,000:
Dep=2,500,000/5 = €500,000

EBIT

EBIT=EBITDA−Dep
Year 1, EBIT=1,460,000−500,000 = €960,000
Year 2, EBIT=2,542,000−500,000 = €2,042,000
Year 3, EBIT=3,634,000−500,000 = €3,134,000

Taxes

Tax=EBIT×0.21
Year 1, Tax =960,000×-0.21 = €201,600
Year 2, Tax = 2,042,000×-0.21 = €428,820
Year 3, Tax = 3,134,000×-0.21 = €658,140

Net Income

Net Income = EBIT−Tax
Year 1, Net Income = 960,000 – 201,600 = €758,400
Year 2, Net Income = 2,042,000 – 428,820 = €1,613,180
Year 3, Net Income = 3,134,000 – 658,140 = €2,475,860

Cash Flow

Cash_Flow = Net + Depreciation
Year 1, Cash_Flow = 758,400 + 500,000 = €1,258,400
Year 2, Cash_Flow = 1,613,180 + 500,000 = €2,113,180
Year 3, Cash_Flow = 2,475,860 + 500,000 = €2,975,860

3-Year Projection

Year	Revenue (€)	OPEX (€)	EBITDA (€)	Net Income (€)	Cash Flow (€)
Year 1	2,160,000	700,000	1,460,000	758,400	1,258,400
Year 2	3,192,000	650,000	2,542,000	1,613,180	2,113,180

Year	Revenue (€)	OPEX (€)	EBITDA (€)	Net Income (€)	Cash Flow (€)
Year 3	4,284,000	650,000	3,634,000	2,475,860	2,975,860

Net Present Value (NPV), Payback

NPV (3 years)

$NPV = \sum CF_t/(1+r)^t$ – Capex

Using r = 10%:

Year 1, $1{,}258{,}400/(1.1)^1$ = €1,144,000
Year 2, $2{,}113{,}180/(1.1)^2$ = €1,746,430
Year 3, $2{,}975{,}860/(1.1)^3$ = €2,237,770

NPV = 1,144,000+1,746,430+2,237,770 = €5.1282M

Payback Period

Year	Cash Flow (€)	Cumulative (€)
0	−2,500,000	−2,500,000
1	+1,258,400	−1,241,600
2	+2,113,180	+871,580
3	+2,975,860	+3,847,440

Payback Period Calculation

After Year 1, cumulative cash flow = −1,241,600

- Remaining to recover: 1,241,600
- Cash flow in Year 2 = 2,113,180

Fraction of Year 2 needed:
Fraction=1,241,600/2,113,180≈0.587 years
Converting into months:
0.587×12≈7.05
So, Payback Period = 1 year 7 months.

4.4. Summary of VPP Financial Viability

- Highly profitable
- Payback < 2 years
- High recurring revenue from markets and subscriptions
- Costs remain stable while revenue scales with energy markets and number of aggregated users

4.5. Business Model Canvas

Key Partners

Universities and Research Centres

- *Access to technical expertise*
- *Collaboration on R&D*
- *Ability to support ongoing development of the application*

Software Firm / R&D Partner

(Equity share or one-time payment model)

- *Development of Android / iOS application*
- *Long-term maintenance and updates*
- *Technical scalability support*

Expertise and Experience Providers

- *Subject-matter experts (energy, IoT, AI, forecasting, optimization)*
- *Advisory roles for validating algorithms and system design*

Motivations for Partnerships

- ***Acquisition of key resources** (technical, academic, financial)*
- ***Access to specialized activities** such as advanced R&D, software development, testing*
- ***Acceleration of product development and innovation***
- ***Shared risk and reduced development cost***

Key Activities

Energy Optimization

This is the core technical activity of the virtual power plant (VPP) or energy management platform. It includes:

- **Forecasting energy demand and generation** using AI/ML models.
- **Optimizing consumption schedules** for households or businesses (e.g., shifting loads to off-peak hours).
- **Managing distributed energy resources (DERs)** such as solar panels, batteries, EV chargers.
- **Reducing overall energy cost** for users by making real-time adjustments.
- **Coordinating flexibility services** for the grid (e.g., demand response). This activity ensures both economic savings and improved grid stability.

User-Friendly Interface

A smooth and intuitive interface is essential for customer adoption. Activities include:

- Designing **mobile and web app interfaces** that are visually simple and easy to navigate.
- Offering **dashboard analytics** for energy usage, cost savings, carbon footprint, and system performance.
- Ensuring accessibility and usability for non-technical users through clear icons, tips, and real-time feedback.
- Continuous UI/UX improvements based on user test results and feedback. This activity makes the technology approachable and increases engagement and retention.

Personalized Services

Providing tailored solutions enhances customer experience. This involves:

- Recommending **individual energy-saving strategies** based on the user's consumption patterns.
- Custom notifications such as:
  - "Best time to run appliances"
  - "Your battery reached optimal charge"
  - "High energy price alert"
- Offering **smart automations** depending on user lifestyle (e.g., work schedules, occupancy).

- Providing user-specific financial insights (ROI, payback period, projected savings). These tailored features increase customer value and differentiate our solution from generic energy apps.

Eco-Friendly Solution

The product aligns with environmental sustainability. Key activities:

- Promoting the use of **renewable energy sources** through optimal scheduling and integration.
- Reducing **carbon emissions** by shifting energy usage to cleaner periods of the grid.
- Encouraging energy-efficient behavior through tips, goals, and progress indicators.
- Supporting the circular economy by integrating storage sharing, community energy, and peer-to-peer trading.
  This aligns the business with the global push for sustainable development and green energy.

Value Propositions

Price Minimization of up to 15%

This refers to the **baseline cost savings** users can achieve simply by optimizing their daily energy usage. The system uses:

- Smart scheduling of appliances
- Load forecasting
- Time-of-use (TOU) price optimization

Even without advanced constraints or market participation, users can save **up to 15%** on their electricity bills through efficient consumption patterns.

Price Minimization of up to 44.1% (Peak Shaving Constraint)

Peak shaving reduces electricity usage during the hours when demand — and prices — are highest. By implementing a **peak shaving strategy**, the system:

- Lowers consumption during expensive peak hours
- Utilizes stored energy (batteries, EVs)
- Reschedules flexible loads

This results in significantly larger savings, achieving **up to 44.1%**, because customers avoid the highest tariff periods.

Price Minimization of up to 66.92% (Providing Ancillary Services)

This represents the highest level of savings because the system not only optimizes internal consumption but also **earns revenue** by participating in external services such as:

- Frequency regulation
- Voltage support
- Demand response programs
- Capacity markets

By providing these ancillary services, the user (or the virtual power plant operator) receives compensation from the grid or the utility. This additional revenue can reduce the net electricity cost by **up to 66.92%**, making it a powerful value proposition for prosumers and microgrid participants.

User-Friendly Interface

A simple, intuitive design makes the platform accessible to users of all backgrounds. The interface:

- Displays energy usage, savings, carbon reduction, and device status
- Provides easy control of appliances
- Offers clear notifications and recommendations

This improves adoption, satisfaction, and long-term engagement.

Personalized Services

The platform adapts to each user's unique lifestyle, consumption pattern, and energy goals. Personalized features include:

- Tailored scheduling recommendations
- Custom alerts (high-price alerts, battery status, usage trends)
- Individual carbon footprint insights
- Customized energy-saving goals

Personalization enhances user value and sets the product apart from generic energy management tools.

Eco-Friendly Solution

Environmental sustainability is an essential value proposition. The solution helps users:

- Reduce carbon footprint
- Use more renewable energy (solar, storage, green power windows)
- Shift consumption to greener grid periods
- Promote cleaner and more sustainable communities

This aligns with global climate targets and ESG priorities.

Social Awareness

The platform promotes energy education and community engagement through:

- Awareness campaigns on sustainable living
- Insights about how user choices affect the environment
- Shared community goals (e.g., "Save 10% Month")
- Encouraging participation in local energy programs

This transforms users from passive consumers into active contributors to energy sustainability.

Customer Relationships

Daily Customer Support and Engagement

The business maintains **continuous interaction** with customers to ensure smooth usage of the energy management or virtual power plant platform. This includes:

- Responding to customer questions and issues **every day**
- Offering **technical support** for app usage, device integration, or energy settings
- Providing **real-time notifications** about energy prices, consumption, and system alerts
- Ensuring customers always feel supported, informed, and connected to the service

Daily engagement helps build trust, reduce churn, and ensure long-term satisfaction.

Personalized Services (Core Relationship Model)

The customer relationship strategy is strongly based on **personalization**, meaning each user gets a tailored experience driven by their own behavior, needs, and preferences. This includes:

- Customized energy use recommendations
- Individual savings reports
- Personalized alerts (high price, peak hours, battery status, solar forecasts)
- Tailored interface and usage insights
- Automated optimization configured to each user's lifestyle

This high level of personalization strengthens the relationship by making the customer feel seen, understood, and valued—creating long-lasting loyalty and differentiation from competitors.

Customer Segments

Commercial VPP Users

These are businesses or industrial clients who participate in a **Virtual Power Plant (VPP)** model that may operate:

- Large commercial buildings
- Factories or warehouses

- Shopping centers
- Data centers

These benefit from:

- Energy cost reductions
- Peak shaving
- Revenue from ancillary services
- Grid flexibility participation

These are typically high-energy users looking for **optimization and financial performance**.

Distribution System Operators (DSOs)

DSOs manage and operate the electricity distribution grid. They are a key segment because they need:

- Better grid balancing
- Demand response resources
- Real-time data on local consumption
- Distributed energy resource (DER) coordination
- Voltage and frequency regulation

The system can support DSOs with:

- Aggregated flexibility
- Predictive analytics
- Enhanced grid reliability

They represent a **high-value B2B customer segment**.

Aggregators

Aggregators combine multiple small energy resources (homes, buildings, DERs) and act as a single unit in the market. They require:

- Optimization tools
- Real-time control
- Market bidding automation
- Asset coordination (batteries, EVs, solar, flexible loads)

The product helps them maximize:

- Market revenue
- Operational efficiency
- Customer participation levels

They are essential players in **modern electricity markets**

Energy Management System (EMS) Users

This segment includes:

- Homeowners
- Small businesses
- Residential solar users
- Smart home users
- Energy-conscious consumers

These users want:

- Cost savings
- Insights into consumption
- Automated control of devices
- Personalized recommendations

These represent the **retail market and mass adoption potential**.

Diversified Market

This refers to the extended audience beyond the core segments, including:

- Municipalities
- Renewable energy communities
- Universities and campuses

- Housing cooperatives
- Smart city projects
- EV fleet operators
- Industrial clusters

Key Resources

Human Resources (Technical & Business Teams)

These are the most critical assets for operating the Virtual Power Plant (VPP) that include:

Technical Team

- Software developers (mobile app, backend, optimization algorithms)
- Data scientists and AI/ML experts
- Energy engineers (VPP design, DER integration, energy markets)
- Cybersecurity specialists
- System integration experts (IoT, smart meters, batteries, EV chargers)

Business Team

- Project managers
- Marketing and sales professionals
- Customer support representatives
- Financial analysts
- Partnership managers

These teams work together to build, maintain, and scale the solution.

Online Channels (Website & Digital Platform)

The website and online interfaces act as key operational resources by enabling:

- Customer acquisition (information, sign-up, marketing funnel)
- User access to the platform
- Distribution of updates, services, and community engagement
- Support/helpdesk communication

They support both daily operations and long-term brand visibility.

Personalized Features

Personalization is a **core intellectual and functional resource** that differentiates our solution. These features include:

- Customized energy recommendations
- AI-driven consumption patterns
- Tailored dashboard analytics
- Alerts based on user behavior and goal tracking
- Smart automation rules

These capabilities increase user value and improve retention.

Intellectual Resources

These are strategic assets that give our business a competitive edge:

- **Patents** (e.g., optimization algorithm, VPP coordination method, or EMS logic)
- **Copyrights** (software, UI design, documentation)
- **Brand identity** (logo, trademarks, corporate reputation)
- **Proprietary datasets**
- **Operational know-how & algorithms**

A patent for our algorithm or application strengthens unique market position and protects our innovation.

Physical Resources

While our solution is mostly digital, some physical resources may include:

- Office space
- Testing hardware (controllers, IoT devices, sensors, smart meters)
- Servers (if not fully cloud-based)
- Laptops and IT infrastructure for staff

These support development, testing, and daily operations.

Financial Resources

Financial capital is crucial for:

- R&D and prototyping
- Patent filing and legal protection
- Software development
- Marketing and customer acquisition
- Cloud hosting and operational costs
- Hiring and talent retention

Funding sources may include investors, grants, and revenue from early adopters.

Channels

The channels describe the solution that reaches customers, delivers value, and provides support. Each channel serves a different customer need and strengthens the overall customer experience.

Online Platform

This is the **primary delivery channel** for the Virtual Power Plant service. It includes:

- Mobile app (Android/iOS)
- Website dashboard
- Customer portal

The online platform enables users to:

- Monitor energy consumption
- View savings and analytics
- Control devices and settings
- Receive alerts, recommendations, and personalized insights
- Perform account management and payments

It is the most scalable and cost-effective channel, allowing global reach and 24/7 interaction.

Telephone Service

A telephone support line provides a **direct and human-centered communication channel** for customers. It is used for:

- Customer service inquiries
- Technical support and troubleshooting
- Onboarding assistance
- Emergency or urgent energy-related issues
- Sales or upgrade support

This channel builds customer trust and ensures users receive immediate help when needed.

In-Person Technician

Some services require **on-site technical support**, especially when dealing with:

- Installation of hardware (controllers, sensors, meters)
- Integration of solar panels, batteries, EV chargers, or IoT devices
- Diagnostic visits to resolve complex issues
- Maintenance and system checks
- Physical upgrades or replacements

This channel ensures reliability and strengthens customer relationships by providing hands-on professional support.

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Cost Structure

The business operates under a **value-driven model**, meaning it prioritizes offering high-quality features, personalized services, and strong user experience—rather than competing only on low cost. As a result, the cost structure includes both significant fixed investments and variable operational costs.

Fixed Costs

These are the costs that remain constant regardless of the number of customers. They are essential to run the service reliably.

a. Human Resources

A core fixed cost, including:

- Software developers
- Data scientists & AI/ML engineers
- Energy engineers
- Cybersecurity specialists
- Sales, marketing, and administrative staff

These salaries represent the primary long-term expenses in a tech-driven energy business.

b. Application Development

One-time or recurring costs related to:

- Mobile app (Android/iOS) development
- Backend, APIs, optimization engines
- UI/UX design
- Continuous updates, bug fixes, and improvements
- QA testing and version releases

This investment ensures that the platform provides advanced features and excellent performance.

c. Server Maintenance Costs

Recurring technical infrastructure expenses:

- Cloud hosting (AWS, Azure, Google Cloud)
- Data storage
- Cybersecurity measures
- Server administration
- API and third-party integration fees

This ensures high availability, real-time performance, and data safety.

Variable Costs

These costs fluctuate based on the number of users or level of service usage.

a. Personalized Services

Personalization requires:

- Additional computation resources
- AI processing and model inference
- Customer support needs
- Increased data storage and recommendation engine usage

As more users join, the cost scales with the volume of personalized analytics and support.
Other variable costs can include:

- In-person technician visits
- Customer acquisition (marketing spend per user)
- Payment transaction fees

Economies of Scale

As the number of users grows:

- The average cost per user decreases
- Server and tech infrastructure become more efficient
- Development costs are spread across more customers
- Profit margins improve

This is typical for software-based businesses: **high initial investment, low marginal cost**.

Economies of Scope

Because the platform can serve multiple customer segments (EMS users, aggregators, DSOs, commercial VPP clients), the business benefits from:

- Shared technology and algorithms
- Reusable data models
- Cross-segment synergies
- Reduced cost of entering adjacent markets

For example, the same optimization engine can serve both residential users and commercial VPP clients with minor adaptations.

Value-Driven Structure

The business is **value-driven** rather than cost-driven. This means:

- High emphasis on personalization
- Investment in a premium user interface
- High-quality service delivery
- Reliable technical performance
- Innovation and continuous development

Users receive **better savings, sustainability benefits, and a superior experience**, justifying the investment in high-value capabilities.

Revenue Streams

The business generates revenue through a combination of **upfront licensing** and **recurring subscription income**. This mixed model is ideal for software-driven energy management systems (EMS) and Virtual Power Plant (VPP) platforms because it provides both **initial capital** and **long-term financial sustainability**.

Initial Application License Fee

This is a **one-time payment** charged at the beginning of the customer relationship. It covers access to the core application and initial setup.

The license fee may include:

- Access to the platform's main features
- Activation of user accounts
- Integration with hardware (smart meters, controllers, IoT devices)
- Configuration of optimization algorithms
- Initial training or onboarding
- Basic support during the installation phase

Benefits of this revenue stream:

- Immediate cash inflow
- Helps recover development and setup costs
- Attractive for B2B customers (commercial VPP users, aggregators, DSOs)
- Supports early-stage scaling and market entry

This model also signals a **premium, high-value product**.

Subscription Model (Recurring Revenue)

This is a **monthly or annual subscription fee** paid by users to continue accessing the service. It creates a stable, predictable revenue stream (MRR/ARR).

Subscriptions can be structured based on:

- Number of users or devices
- Level of personalization
- Access to advanced analytics
- Participation in ancillary services
- Cloud data storage

- Premium features (e.g., AI-driven automation, peak shaving optimization)

Advantages:

- Continuous revenue over the customer lifetime
- Predictable cash flow
- Encourages long-term customer relationships
- Scales easily as the user base grows
- Allows tiered pricing (basic, premium, enterprise)

Conclusions

The prototype of the VPP Control is composed of 2 sections. The first part consisted of optimizing the energy interchange between the VPP and the MG to reduce electricity bill by creating new set points of operation of the elements included in the MGs such as Energy Storage Systems and EVs. The second part consisted of designing a GUI based digital twin of the VPP in which the number of MGs and VPPs along with the elements can be modified according to the needs of the user. This digital twin can optimize the results based on the algorithm of the first part and display the results in a very user-friendly manner so that it is easy to understand. The future work will include creating an infinite number of MGs that can be modified according to the user's input and be able to optimize the results instantaneously. This will be particularly helpful in setting up a new factory or a residential house in the existing grid and observe the effects of the new establishment. Also, selecting the right capacity of EMS for the new establishment can be also identified from the results.

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5. IRP04 – Condition Monitoring for Smart Power Electronic Converter Systems for Distributed Generation

5.1. Introduction

Predictive maintenance is emerging as a key enabler for improving reliability and reducing the operational expenditure of large-scale photovoltaic (PV) assets. However, traditional adoption is often constrained by high upfront investment, limited data accessibility, and unclear returns on predictive analytics. This work proposes a performance-driven, risk-sharing business model that integrates advanced condition monitoring, digital diagnostics, and edge-computing capabilities to deliver measurable improvements in system availability and maintenance efficiency. Instead of conventional subscription-based pricing, the model aligns economic incentives by directly linking compensation to verified reductions in downtime and maintenance costs, thereby lowering the financial and operational barriers for operation and maintenance (O&M) contractors. The proposed framework includes structured data acquisition, on-site diagnostics, health-indicator classification, and targeted maintenance recommendation workflows, all while ensuring secure data handling through local computation and controlled data flows. A comprehensive assessment of key activities, stakeholder relationships, cost–revenue mechanisms, and potential risks demonstrates that this model offers a scalable and mutually beneficial pathway for accelerating the adoption of predictive maintenance in modern solar power plants.

The objective of this work is to develop and evaluate a performance-driven predictive maintenance framework for large-scale PV installations, integrating advanced condition monitoring, edge-based diagnostics, and a risk-sharing business model that aligns financial incentives with measurable improvements in system reliability and O&M cost reduction.

5.2. Background

The global maintenance market for large-scale solar power plants is experiencing significant expansion, driven by the rapid deployment of photovoltaic (PV) installations worldwide. Recent market analyses indicate that the value of this sector reached 1141 GW in 2023, and is projected to grow substantially, potentially attaining 5457 GW by 2030 as solar power penetration continues to increase [1]. This trend underscores a growing demand for more efficient and cost-effective maintenance strategies capable of maintaining high system availability amid aging assets and expanding operational portfolios.
At present, maintenance activities in large-scale solar power assets rely predominantly on corrective maintenance and preventive maintenance approaches [2]. These two methods are illustrated in Fig. 1. Corrective maintenance follows a "run-to-failure" strategy, which results in extended downtime, higher risk of cascading failures, and increased operational losses [3]. Preventive maintenance, while reducing catastrophic failures, often adopts rigid, time-based replacement schedules, leading to material waste and elevated O&M expenditure due to the premature replacement of components in a healthy statue [3].

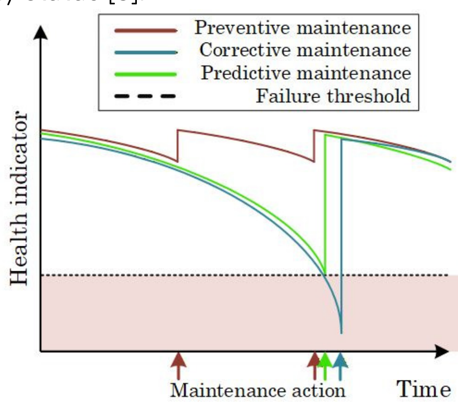

Fig. 1: Comparison between preventive-, corrective-, and predictive maintenance [4]. The health indicator reduces gradually with time, and it fails once the health indicator is below the threshold. The preventive maintenance requires more actions; while the corrective maintenance needs to work till failure. The predictive maintenance provides a balanced option between maintenance actions and system reliability.

To balance reliability and cost, predictive maintenance has emerged as a promising strategy that dynamically schedules interventions based on equipment condition rather than fixed intervals [2][3]. According to industrial market reports, predictive maintenance remains in an early but rapidly evolving stage, supported by advancements in sensing technology and data analytics [5]. The predictive maintenance market is expected to grow to USD 60 billion by 2030, demonstrating strong commercial interest and technological momentum [6], [7].

More recently, commercial vendors have introduced subscription-based predictive maintenance services, where operators pay a fixed recurring fee for diagnostic capabilities and remote monitoring tools. Although this model simplifies budgeting, it often lacks alignment between costs and actual performance outcomes, and may still require substantial upfront investment in sensing or digital infrastructure. As a result, subscription-based pricing has not fully resolved barriers related to uncertain return on investment (ROI) or limited incentives for continuous reliability improvement.

Despite its potential, the widespread adoption of predictive maintenance faces challenges related to high upfront investment, data accessibility, and unclear return on investment (ROI). To address these barriers, a new business model has been developed to align economic incentives across stakeholders, particularly between operation and maintenance (O&M) contractors and predictive maintenance solution providers. This model aims to reduce adoption reluctance, expand coverage, and enable scalable deployment across large solar power portfolios.

5.3. Key Activity of the Predictive Maintenance Service

The core activities of the proposed business model focus on the secure acquisition, processing, and interpretation of

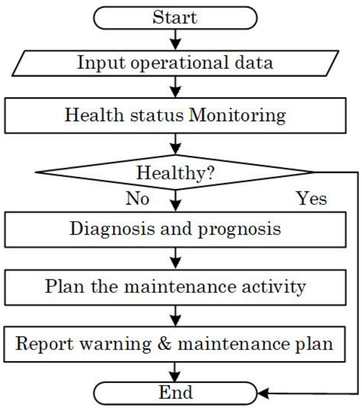

Fig. 2: PdM service workflow of processing the operational data to estimate the health status and plan health-condition-based maintenance.

operational data to enable accurate and timely predictive maintenance decisions, as illustrated in Fig. 2.

First, operational and environmental data are collected from power plant components, including PV inverters and associated critical devices that affect system operation and reliability [8]. To enhance diagnostic accuracy, additional sensors are deployed when existing operational sensors do not provide sufficient granularity to detect early-stage degradation or failure precursors. These sensors feed data to edge-computing devices equipped with advanced diagnostic algorithms.

The edge-computing platform operates a software toolset capable of extracting health indicators, classifying degradation patterns, and generating failure predictions based on historical data and embedded failure mechanism models. The device also incorporates a local database, allowing the system to reference known degradation signatures and continuously refine its assessments. By performing on-site computation, the solution ensures low-latency detection and addresses cybersecurity concerns associated with remote data transmission.

Once degradation or elevated failure risk is identified, the system translates these findings into maintenance recommendations, balancing component health status with expected impacts on operational continuity and maintenance cost. Recommendations are communicated to the O&M contractor through a structured notification system, enabling proactive and cost-efficient maintenance scheduling. This workflow strengthens coordination between the predictive maintenance service provider and the O&M team, supporting timely interventions that minimize downtime and reduce unnecessary material replacement.

5.4. Customer Relationship

The success of this business model relies on establishing long-term, collaborative, and performance-oriented relationships with operation and maintenance contractors. These relationships are inherently bidirectional (as seen in Fig. 3): O&M contractors provide access to solar power generation assets, operational data streams, and historical maintenance records, all of which serve as essential inputs for accurate health assessment and predictive diagnostics [8]. In return, the predictive maintenance provider delivers data-driven insights that enhance system availability, increase energy yield, and reduce maintenance costs, creating tangible operational value for the contractors.

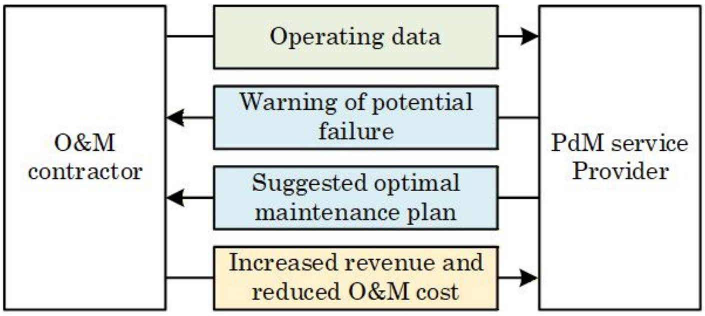

Fig. 3: The O&M provides data, and then the predictive maintenance (PdM) service provider gives health monitoring results, including potential failures and optimal maintenance plan. At the end, PdM service provider gains revenue from enhanced system performance.

Unlike conventional vendor–client arrangements, the proposed business model adopts a risk-sharing framework, eliminating the need for upfront investment or subscription fees. Instead, compensation is tied to the verified reduction in downtime and maintenance expenditures, which fosters trust and strengthens alignment between stakeholders. This structure not only lowers the adoption barrier for O&M contractors but also motivates the predictive maintenance service provider to continuously refine diagnostic tools and maintain high solution performance.
Through this collaborative approach, stakeholders form a unified ecosystem that supports accurate fault detection, informed maintenance planning, and dependable field execution. By integrating predictive insights directly into the operational workflow of O&M contractors, the model enhances reliability management practices and establishes a scalable foundation for long-term partnership and shared operational benefits.

5.5. Cost and Revenue

The cost structure of the proposed business model comprises both development-stage expenditures and operational-stage expenditures, including both hardware and software usage in predictive maintenance solutions. During the development stage, costs arise from the procurement of additional sensing hardware, edge-computing platforms, and communication modules required to support failure prediction alarm. Parallel to this, significant investment is required in software development, including diagnostic algorithms, failure mechanism analysis models, and maintenance decision-planning tools. These activities rely heavily on skilled human resources, such as hardware engineers, software developers, and data scientists, to ensure accurate model construction and seamless system integration.
In the operational stage, both hardware and software components require continuous calibration, verification, and updates to maintain high diagnostic accuracy and enable timely identification of potential failures. Edge devices and sensors must be periodically tested, while analytics models require continuous refinement based on newly observed degradation patterns. These ongoing requirements contribute to operating expenditure (OPEX), together forming the full lifecycle cost profile of the business model.
Revenue is generated through a shared-savings mechanism, in which the O&M contractor pays a proportion of the financial gains realized from reduced downtime, optimized maintenance activities, and lowered material replacement costs. This structure transforms predictive maintenance into a performance-driven service, ensuring that the financial burden on the contractor is proportional to measurable and verified benefits. In addition to the shared-savings model, optional revenue streams include premium service tiers, such as advanced diagnostic subscriptions or enhanced operational dashboards that offer deeper asset insights and further reduce maintenance time. The pricing structure can also scale with the size and operational complexity of the power plant portfolio, enabling flexible deployment across diverse customer segments.

5.6. Risk assessment

The implementation of the proposed predictive maintenance business model involves several technical, operational, and commercial risks. To ensure long-term viability, these risks must be systematically evaluated and addressed through appropriate mitigation strategies. Table 1 summarizes the major risks and corresponding solutions.

Table 1. Key Risks and Mitigation Strategies

Risk	Description of Risk	Mitigation Strategy
Insufficient maintenance cost reduction	The improvement achieved through predictive maintenance may not be sufficient to justify operational expenses or support the financial sustainability of the business model [9].	• Continuously refine diagnostic algorithms using real-world data [10]. • Deploy targeted sensing to increase detection accuracy. • Start with pilot projects to validate ROI before scaling.
Data security concerns	O&M contractors may be reluctant to share operational data due to cybersecurity risks or data ownership considerations.	• Provide edge-only deployment with local data storage. • Implement strong encryption and access control policies. • Employ dedicated cybersecurity engineers and perform regular penetration testing.
Resistance from O&M contractors	Contractors may fear workflow disruptions or increased operational complexity.	• Offer training sessions and intuitive dashboards. • Ensure integration with existing maintenance processes. • Highlight zero-upfront-cost and shared-savings benefits.
Hardware reliability issues	Additional sensors or edge devices may fail or degrade, reducing system performance.	• Use industrial-grade, certified hardware. • Implement periodic device diagnostics and redundancy where needed. • Provide rapid replacement and support service.
Model performance Degradation over time	Predictive models may become less accurate due to changing operational conditions or new failure modes.	• Schedule periodic model retraining with updated field data. • Use adaptive and self-learning algorithms. • Maintain historical libraries of failure signatures for continuous improvement.
Integration challenges with existing SCADA/EMS	Legacy systems may limit data availability, compatibility, or communication bandwidth.	• Develop modular APIs and communication interfaces. • Provide on-site integration support. • Utilize lightweight edge analytics to minimize dependence on SCADA throughput.
Regulatory or compliance constraints	National or regional regulations may restrict data handling or remote diagnostics.	• Comply with IEC 62443, GDPR, and local grid codes [11]. • Keep all sensitive data on local servers when required. • Maintain transparent documentation for audits.

5.7. Conclusion

The proposed business model introduces a performance-driven predictive maintenance framework designed to enhance reliability and reduce operation and maintenance (O&M) costs for large-scale solar power assets. By leveraging advanced diagnostic analytics, condition monitoring, and edge-computing technologies, the model provides O&M contractors with data-driven insights that enable timely, targeted maintenance actions, thereby minimizing downtime and preventing unnecessary component replacements.

Unlike traditional maintenance service structures, the model adopts a risk-sharing and value-aligned revenue mechanism, in which compensation is tied directly to verified improvements in system performance. This approach not only reduces the financial barrier for O&M contractors, who are not required to make upfront investments, but also creates strong incentives for continuous algorithm enhancement and high-quality service delivery.

By combining technological innovation with an economically aligned contractual framework, the proposed model establishes a scalable and mutually beneficial foundation for modernizing maintenance practices in large-scale PV installations. This integration of reliability improvement, cost reduction, and shared financial benefits positions the model as a promising pathway for accelerating the adoption of predictive maintenance across the solar power sector.

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SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

6. General Conclusions

The four Individual Research Projects developed within Work Package 2 collectively demonstrate the technical maturity and market relevance of next-generation distributed energy solutions. Each IRP addresses a different but complementary element of the distributed energy value chain: advanced inverter hardware for resilient microgrids, open and vendor-neutral energy management for prosumers, coordinated control of aggregated assets through virtual power plant technologies, and performance-driven predictive maintenance for large-scale PV installations. Together, they form a coherent set of tools that can improve the flexibility, reliability, and economic performance of renewable energy systems.

The results highlight that hardware innovation alone is no longer sufficient; meaningful progress requires the integration of digital intelligence, modular architectures, and data-driven decision-making. The business models proposed in the IRPs emphasize affordability, interoperability, and transparent value creation—key factors for the widespread adoption of distributed energy technologies across residential, commercial, and utility-scale sectors. Moreover, the techno-economic analyses included in the IRPs confirm that these approaches can be financially viable, scalable, and aligned with evolving energy policies.

Overall, WP2 contributes a robust foundation for future research and innovation in distributed renewable energy systems. The work supports the broader goals of SmartGYsum by connecting technical advancements with practical, market-oriented solutions that can accelerate the transition toward a more flexible, efficient, and resilient energy ecosystem.