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CURRENT SITUATION AND DEVELOPMENT PERSPECTIVES OF PHOTOVOLTAIC INSTALLATIONS, WITH AND WITHOUT ENERGY STORAGE

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Abstract ***This paper analyzes the current situation and development perspectives of photovoltaic (PV – Photovoltaic) systems in Romania, with and without energy storage (ESS – Energy Storage Systems) . The study highlights the role of the national and European legislative frameworks in supporting the transition toward renewable energy and the integration of energy storage systems. The analysis is based on recent reports and official documents from ANRE, IRENA, the European Commission, and other authoritative sources.***

Keywords: photovoltaic systems, energy storage, Romania, renewable energy, legislative framework, Li-ion batteries, energy transition.

1. INTRODUCTION

Romania has experienced accelerated growth in photovoltaic capacity, reaching over 3 GW by 2024, driven by programs such as Green Photovoltaics Program, the modernization fund, and EU-supported CfD (Contracts for Difference) mechanisms. The research identifies two main categories of PV systems: on-grid systems, characterized by low costs and high efficiency but dependent on grid stability, and hybrid/off-grid systems, which provide autonomy and flexibility through battery integration, albeit with higher initial investment costs.

The comparison between these system types demonstrates that decreasing battery prices (over 70% reduction between 2013–2024) and new legislation mandating energy storage for prosumers (Law 255/2024) will significantly influence market dynamics. Despite the country's high solar potential (1,200–1,600 kWh/m²/year), challenges persist due to insufficiently modernized grid infrastructure and complex administrative procedures.

The paper concludes that Romania's photovoltaic sector is entering a phase of structural maturity. Continued grid modernization, digitalization, and long-term financial mechanisms such as CfD will be essential for sustaining growth. If these measures are effectively implemented, Romania is well-positioned to become a regional hub for solar energy production and storage in Eastern Europe by 2030.

1.1 Global and european context of the energy transition

Climate change, the increasing energy demand, and the volatility of fossil fuel markets have prompted the international community to accelerate the adoption of renewable energy sources [1]. The European Union (EU) responded through the European Green Deal and the "Fit for 55" legislative package, establishing a target of at least 55% reduction in greenhouse gas emissions by 2030 and achieving climate neutrality by 2050 [2]. Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources set a minimum target of 32% renewable energy in gross final energy consumption, later revised to 42.5% through the 2023 agreement [3].

Solar photovoltaic (PV) energy has become one of the strategic pillars of the energy transition, due to its scalability and the continuous decrease in technological costs [4]. The 2024 IRENA report indicates a reduction of over 85% in PV module costs compared to 2010 [5], while Li-ion battery storage has recorded an 83% price decrease over the same period [6].

1.2 National legislative framework

Romania has committed, through its National Integrated Energy and Climate Plan (PNIESC), to achieving a 30.7% share of renewable energy in gross final energy consumption by 2030 [7]. The Romanian Energy Strategy 2025–2035 targets the development of over 6 GW of photovoltaic capacity and the deployment of 1.2 GW of energy storage to support balancing services and grid flexibility [8].
Recent legislative measures with significant impact on the PV sector include:

- Offshore Law 2024 – enables the development of renewable energy projects in offshore areas and on existing infrastructure [9];
- Government Emergency Ordinance (GEO) 134/2024 – eliminates double taxation of stored and re-injected energy [10];
- ANRE Methodology 2025 – exempts re-injected stored energy from certain tariffs and green certificate obligations [11];
- Law 255/2024 – requires prosumers with systems between 3–400 kW to include energy storage: at least 30% for 3–200 kW and 50% for 200–400 kW [12];
- ANRE Orders 15/2022 and 4/2023 – simplify grid connection procedures for prosumers and introduce quantitative compensation (net-metering) [13];
    - GEO 143/2023 – facilitates the participation of energy communities and aggregators in the national energy market [14].

1.3 Support programs and financial instruments

The Green Photovoltaics Program, managed by the Environmental Fund Administration (AFM), provides non-refundable grants of up to 20,000 RON for residential installations, contributing to the deployment of over 500 MW between 2019 and 2023[15].

The Modernization Fund, NRRP (National Recovery and Resilience Plan), and Just Transition programs also support large-scale photovoltaic projects, both with and without storage, offering funding of up to EUR 750,000/MW for PV systems between 200 kW and 1 MW, and EUR 425,000/MW for projects exceeding 1 MW [16].

In March 2024, the European Commission approved a EUR 3 billion support package in the form of Contracts for Difference (CfD), strengthening long-term investment predictability [17]. These measures enhance investment stability, reduce market risk, and encourage energy storage integration. Romania has an average solar potential of 1,200–1,400 kWh/m²/year in most regions, with peaks in Dobrogea and southern Oltenia, placing it among the European countries with competitive solar resources [18]. With accelerated investment and the effective implementation of support policies, Romania can meet and even exceed the PNIESC targets, provided that grid modernization and large-scale storage solutions are adopted [19].

1.4 Objectives of the article

This review-type article aims to:

- Analyze the legislative framework and strategic policies governing the development of photovoltaic power plants with and without energy storage in Romania;
- Highlight the advantages and limitations of each system category;
- Identify the development challenges and opportunities based on recent studies and reports;
- Compare Romania's trends with those observed in other European countries.

A brief methodological clarification: the legislative, technical, and market information analyzed in this article was selected based on three criteria — chronological relevance (2018–2025), regulatory impact on PV and ESS deployment, and source reliability. Only verified institutional sources such as ANRE, IRENA, the European Commission, the Ministry of Energy, IEA, and BloombergNEF were used to ensure consistency and comparability across datasets.

2. PHOTOVOLTAIC SYSTEMS WITH AND WITHOUT ENERGY STORAGE SYSTEMS (ESS)

2.1 General Context

The development of photovoltaic systems is rapidly increasing due to technological cost reductions and supportive energy transition policies [4], [6]. Their classification into systems without storage (on-grid) and systems with storage (hybrid/off-grid) reflects differences not only in technology, but also in economic and legislative frameworks [20].

2.2 Photovoltaic Systems Without Storage (On-Grid)

These systems operate by converting solar radiation into direct current (DC), followed by conversion into alternating current (AC) synchronized with the grid. The generated energy is consumed in real time, while any surplus is injected into the public distribution network [5], [21].

Advantages:

- Low initial cost [22]
- High efficiency for well-matched consumption profiles [23]
- Low maintenance requirements [24]

Limitations:

- Lack of autonomy during grid outages [25]
- Dependence on compensation schemes (net-metering / net-billing) [26]

2.3 Photovoltaic systems with storage (Hybrid/Off-Grid)

These systems include batteries for storing the generated energy. Hybrid systems operate while connected to the grid, whereas off-grid systems function independently [27], [28].

Advantages:

- Increased self-consumption rate (up to 80%) [29]
- Continuous power supply, including during outages [30]
- Optimization of energy use during peak-tariff periods [31]

Limitations:

- High initial cost and the need for an advanced
- Battery Management System (BMS) [32]
- Limited battery lifespan (10–15 years) compared to PV modules [33]

2.4 A synthetic comparison between systems with and without energy storage is presented in **Table I**.

Table I. Source: adapted from [25], [30], [32], [35]

Characteristic	Without storage (On-Grid)	With storage (Hybrid/Off-Grid)
Initial cost	Low	Medium–High
Energy autonomy	No	Partial or Complete
Self-consumption rate (%)	25–35%	60–80%

Power supply continuity	No	Yes
Maintenance	Low	Medium
Estimated payback period	5–7 years	8–12 years

2.5 Applicable legislative framework in Romania

In Romania, incentive mechanisms include quantitative compensation (net-metering) for installations of ≤200 kW and financial compensation for those up to 400 kW, in accordance with ANRE Orders 4/2023 and 107/2023 [34]. Law 255/2024 mandates the integration of energy storage systems for installations between 3 and 400 kW by December 31, 2027 [35].

2.6 Final remarks

On-grid systems remain an affordable solution in urbanized areas with a stable grid. However, the declining cost of batteries and the legislative push toward energy autonomy are increasingly driving both consumers and investors toward hybrid solutions, which are more robust and resilient.

3. EVOLUTION OF THE PHOTOVOLTAIC MARKET IN ROMANIA

3.1 Current situation and recent trends

At the end of 2023, Romania had an installed photovoltaic capacity of approximately 1,545 MW, according to ANRE, including both prosumer systems and industrial-scale projects [33]. During 2024, the national PV sector recorded the highest annual growth so far, adding approximately 1.7 GW of new capacity. As a result, Romania reached a total installed PV capacity of around 3.24 GW by the end of 2024 [36].

In situations where numerical values for installed capacity or technological costs differ between sources by 3–7%, the paper adopted as reference the data published by ANRE until 2024, explicitly mentioning the variations existing in the specialized literature. This approach ensures consistency of interpretation and reduces ambiguities generated by different reporting methodologies.

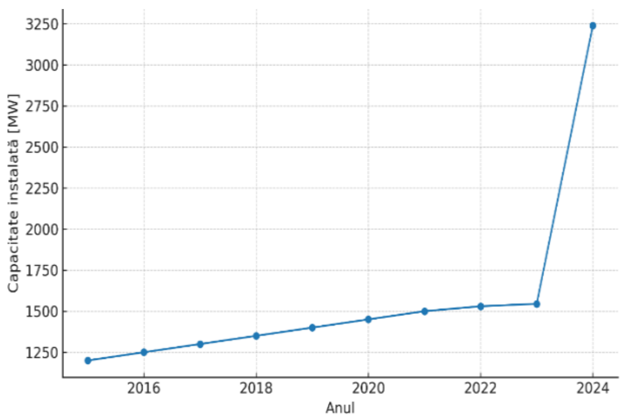

Figure 1 - The evolution of installed photovoltaic capacity in Romania between 2015 and 2024.

3.2 Major Obstacles

Although Romania's solar potential is high (1,400–1,600 kWh/m²/year in Dobrogea and Oltenia) [37], development is constrained by:

- Electric grid infrastructure, which requires modernization and digitalization;
- Complex administrative procedures;
- Lack of stable long-term financial support schemes [8].

3.3 Solutions and Development Pace

The introduction of energy communities, the implementation of Contracts for Difference (CfD), and energy storage programs can significantly accelerate market growth[38]. At the European level, the installation rate has shown a steady increase, as illustrated in Figure 2.

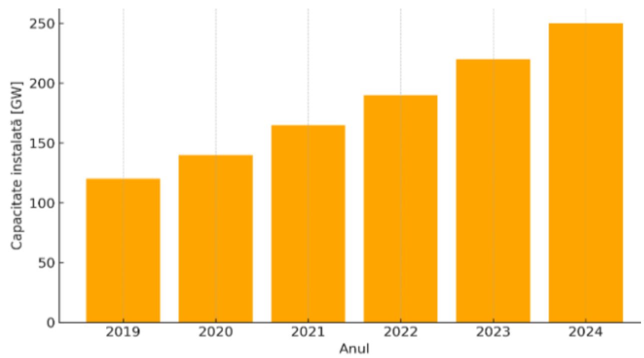

Figure 2 – Evolution of Installed Photovoltaic Capacity in the EU (2019–2024)

3.4 Comparison with other European countries

In 2024, the share of solar energy in Romania's electricity production was 12.7%, compared to the EU average of 14% [40]. Poland had an installed capacity of 20.2 GW, Hungary reached 7.7 GW, while Romania recorded 3.24 GW following the 2024 expansions.

3.5 Evolution of battery costs and impact on the PV market

The price of $LiFePO_4$ batteries has decreased by over 70% between 2013 and 2024, driving increased interest in PV systemswith energy storage. The trend of average Li-ion battery prices is illustrated in Figure 3.

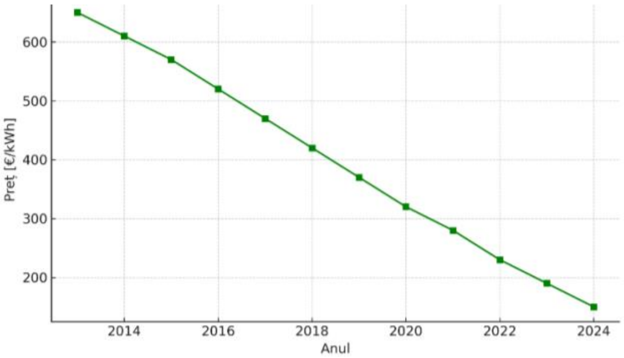

Figure 3 – Evolution of the Average Li-ion Battery Price (€/kWh), 2013–2024

3.6 Critical discussion: Technical, Economic, and Policy Barriers

Although Romania has recorded significant progress in photovoltaic deployment, several structural challenges may hinder future development:

Technical limitations:

- The national transmission and distribution grid operates close to its maximum hosting capacity in several regions, especially in southern and southeastern Romania.
- Voltage fluctuations and reverse power flows increasingly affect local distribution networks, limiting the connection of new prosumers.
- Insufficient digitalization and lack of advanced monitoring systems reduce the capacity to manage intermittent PV production effectively.

Economic barriers:

- The volatility of equipment prices—PV modules, inverters, and especially batteries—creates uncertainty for investors.
- Long-term financing instruments remain limited, particularly for medium-sized industrial projects.
- The payback period for PV+ESS systems is still perceived as relatively long by residential consumers.

Policy and administrative risks:

- Frequent legislative changes may discourage long-term investment planning.
- Project authorization procedures remain complex, with multi-stage approvals at local and national levels.
- Delays in grid reinforcement projects risk creating bottlenecks that slow down the adoption of large-scale PV plants.

These challenges underline the need for a coordinated national approach, combining legislative stability, targeted financial support, and accelerated grid modernization.

3.7 Discussion and analytical insights

The analysis of Romania's photovoltaic development indicates strong alignment with European strategic objectives; however, several structural challenges may influence the pace of the transition. A sensitivity assessment based on projected PV growth, battery price evolution, and grid modernization scenarios highlights the following considerations:

a) Grid absorption capacity

Under a moderate-growth scenario (500–700 MW/year), the current distribution infrastructure may continue to accommodate new PV capacity with localized reinforcements. In a high-growth scenario (>1 GW/year), substantial investments in digital substations, storage integration, and curtailment management will be required.

b) Battery cost trajectory

If Li-ion prices continue to decline at an annual rate of 8–12%, hybrid residential systems may achieve payback periods close to 6–8 years, making them competitive with on-grid systems. Conversely, in a stagnation scenario, ESS adoption may rely heavily on subsidies and regulatory mandates.

c) Legislative stability

The positive impact of recent laws (Law 255/2024, GEO 134/2024) is contingent upon stable implementation and clear secondary legislation. Any delay may reduce investor confidence and slow deployment.

d) Market behavior of prosumers

Comparative analysis with Poland and Hungary shows that prosumer adoption is strongly correlated with compensation mechanisms. If Romania maintains quantitative compensation and gradually transitions to dynamic pricing, self-consumption could rise from 35% to 55% even without additional storage.

e) Risk factors

Key risks include:

- administrative delays in grid connection approvals,
- unpredictability of support schemes,
- supply-chain fluctuations for inverters and batteries.

Overall, Romania's PV sector shows strong potential, but sustained growth depends on coordinated policy, financial stability, and accelerated grid modernization.

4. CONCLUSIONS

4.1 Main findings

a) Accelerated growth of installed capacity – In 2024, Romania recorded its highest annual installation rate to date, surpassing the 3 GW total capacity threshold [40].

b) Emerging role of energy storage – The over 70% reduction in Li-ion battery prices over the past decade [41] has created favorable conditions for the large-scale deployment of PV systems with storage.
c) Legislative pressure – Recent regulatory changes (Law 255/2024) mandate the integration of minimum storage capacities for prosumers by 2027 [35].
d) Infrastructure deficiencies – The national transmission and distribution network requires significant investment to accommodate the increasing volume of renewable energy [38].

4.2 Strategic perspectives

a) Digitalization and grid modernization will be essential for managing production fluctuations and integrating energy storage systems.
b) Stable long-term support schemes, such as Contracts for Difference (CfD), will attract institutional investors and ensure financial predictability.
c) The creation of energy communities will foster local self-consumption and reduce grid losses.
d) The integration of ESS (Energy Storage Systems) in new projects will enhance energy resilience and allow cost optimization through energy use during high-price periods.

4.3 Author's Recommendations

a) Simplify authorization procedures for PV and ESS projects.
b) Establish dedicated programs to support residential and industrial storage investments.
c) Align grid development plans with the PNIESC 2030 objectives.
d) Enhance collaboration between authorities, grid operators, and the private sector to implement efficient renewable energy integration solutions.

4.4 General Conclusion

If Romania continues its current growth trajectory, supported by coherent policies and infrastructure investments, it is realistic to expect that by 2030, the country could become a regional hub for solar energy production and storage in Eastern Europe.

The conclusions highlight that the integration of ESS can significantly increase the economic and operational performance of photovoltaic installations, increasing self-consumption up to 70–85% and reducing the pressure on the distribution network. The evolution of battery costs, estimated in the literature as a reduction of 25–40% by 2030, will intensify the adoption of storage technologies in residential and commercial projects. To accelerate the energy transition, it is necessary to strengthen the legislative framework on flexibility, the introduction of dynamic tariffs and the integration of ESS into auxiliary services of the energy system.

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