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THE DEVELOPMENT OF SOLAR GENERATION IN THE CONTEXT OF THE EU "GREEN DEAL"

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The article analysis the role of solar energy in achieving the EU's strategic targets. Against the backdrop of the global task of tripling renewable energy capacity and doubling energy efficiency, disparities in the share of renewables between countries are revealed, which stimulates the search for new growth sources, including photovoltaics even in northern regions.
The aim of this work is to assess the projected potential for electricity production from PV in the EU as a whole and in Lithuania in particular, taking into account technological progress, decreasing system costs, the spread of energy communities, support for producers and consumers, as well as the deployment of corresponding storage systems.
The proposed methodology combines a review of information sources with scenario modeling of solar energy development (baseline, accelerated, and restrictive scenarios) and sensitivity analysis of key drivers: insolation, the dynamics of storage capacity growth, and the use of regulatory incentives.
The expected results show that, provided support programs are expanded, energy communities are developed, and storage systems are deployed together with photovoltaic systems, solar energy could make a substantial contribution to achieving the target of 45% renewables in total final energy consumption.
The practical value of this research lies in providing a reproducible framework scenario for Northern European countries and specific recommendations for Lithuania.

Keywords: *solar energy, photovoltaics (PV), renewable energy, gross production of electricity, forecasting models*

INTRODUCTION

Global challenges to the sustainable development of society and the world economy highlight the necessity and importance of renewable energy. Key documents, such as the United Nations Sustainable Development Goals (SDGs) to 2030 (UNDP, 2023), the European Bioeconomy Strategy (2012, updated in 2018) (European Commission, 2018), and the European Green Deal (European Commission, 2019), aim to accelerate the transition to renewable energy and a circular economy. The updated EU Energy Security Strategy to 2030 envisages an increase in the share of renewable energy sources in the consumption structure up to 45% (European Commission, 2014; Directive, 2018). According to the European Green Deal, by 2030 greenhouse gas emissions must be reduced by 55% compared to 1990 levels, while ensuring sustainable economic growth without increasing fossil fuel use. This also requires raising the share of renewable energy (Kukharets et al., 2023) and improving energy efficiency.

Renewable energy sources are a key element of sustainable development, the greening of the global economy, energy accessibility, and the resilience of energy security (Atstāja, 2025; Arias, Feijoo, & Moreira, 2023). The transition to renewable energy, with a greater share of "green" energy in total consumption, enables the realization of several Sustainable Development Goals: ensuring affordable and clean energy, supporting economic growth and innovation, building sustainable communities, encouraging responsible production and consumption, mitigating climate change, and strengthening partnerships (Obaideen et al., 2021; Green World Energy, n.d.).

Among these, solar energy currently accounts for about 5% of global electricity production and demonstrates steady growth, driven by decreasing system costs, technological improvements, and the implementation of support mechanisms for solar projects (Mandys, Chitnis, & Silva, 2023; IEA, 2023; Kukharets et al., 2024).

However, as IRENA (2024) indicates, by 2023 it became problematic to achieve the key global targets of tripling renewable energy capacity and doubling energy efficiency by 2030. In 2023, Sweden and Finland had a share of renewable energy sources in total consumption above 50%, while Denmark, Latvia, Estonia, and Austria exceeded 40%. In contrast, most EU countries remained at 30% or below (Eurostat, 2024; IRENA, 2024). To ensure reaching the indicative target of

45% renewables in the total consumption balance, EU countries must advance to a new level of renewable resource utilization, including those previously considered less rational for specific states. It is also essential to assess the impact of such changes on the sustainable development index, as confirmed by comparative analyses of various RES types (Wang, Zhang, Li, & Chen, 2025; Saha, 2024).

In the Baltic region, solar energy was long not considered a priority due to climatic constraints. However, energy independence from the BRELL system, achieved in 2025, spurred a significant increase in the number of "prosumer" households in Lithuania (Elsun, 2024). The government actively promotes decentralized generation through tax incentives, subsidies, and support for energy communities. Nevertheless, to substantiate the scale of funding required for solar energy development, forecasting of solar energy potential remains essential.

In this study, Eurostat statistics (Eurostat, 2024) were used for analysis. Based on these data, three mathematical models were developed to describe the change in gross production of electricity from photovoltaic power plants (GPESP) in EU countries over a long-term period.

RESEARCH METHODS

To model the long-term dynamics of changes in GPESP, three models were applied (Kukharets et al., 2022; Eurostat, 2024). The first model is based on the assumption that the change in electricity production is proportional to electricity production and time:

$$\frac{dE}{dT} = k_{ET} ET \ , \ \frac{dE}{E} = k_{ET} T dT \ , \tag{1}$$

where E – electricity production from photovoltaics, Gigawatt-hour;
T – time, years;
k_{ET} – proportionality coefficient for production and time.

After solving equation (1), the following formula is obtained:

$$E = E_0 \exp\left[\frac{k_{ET}}{2}\left(T^2 - T_0^2\right) \right] .$$

The proportionality coefficient for production and time can be calculated by the following formula:

$$k_{ET} = \frac{2}{T^2 - T_0^2} \ln \frac{E}{E_0} \ . \tag{2}$$

The second model assumes that the change in electricity production is proportional only to electricity production:

$$\frac{dE}{dT} = k_E E \ , \ \frac{dE}{dT} = k_E dT \ , \tag{3}$$

where k_E – proportionality coefficient for electricity production.

After solving equation (3), the following formula is obtained:

$$E = E_0 \exp\left[k_E \left(T - T_0\right) \right] .$$

The proportionality coefficient for electricity production can be calculated by the following formula:

$$k_E = \frac{1}{T - T_0} \ln \frac{E}{E_0} . \tag{4}$$

The third model assumes that the change in electricity production is proportional only to time:

$$\frac{dE}{dT} = k_T T \ , \ dE = k_T T dT \tag{5}$$

where k_T – proportionality coefficient for time.

After solving equation (5), the following formula is obtained:

$$E = E_0 + \frac{k_T}{2}\left(T^2 - T_0^2\right)$$

The proportionality coefficient for time can be determined by the following formula:

$$k_E = 2\frac{E - E_0}{T^2 - T_0^2}; \tag{6}$$

In further calculations, the proportionality coefficients were determined through integral dependencies that take into account the initial and final values of electricity production for the analysed period. The obtained equations allow quantitative assessments of the dynamics and forecasts for the medium-term perspective.

RESEARCH RESULTS AND DISCUSSION

Based on statistical indicators (Eurostat, 2024) and the proposed models, an assessment and forecast of the development of Gross Production of Electricity from solar photovoltaic power plants (GPESP) were performed. This assessment and forecast were made for the European Union, Lithuania, and Germany.

It should be noted that for the forecast calculations according to the proposed mathematical models, empirically determined coefficients were used, as shown in Table 1.

Table 1. Empirical coefficients and equations for the corresponding GPESP dynamics models

Model description	*Coefficient*	*Country*	*Value*	*Equation*
Change in electricity production proportional to energy and time	k_{ET}	Lithuania	$5.138 \cdot 10^{-5}$	$E = E_0 \exp\left[\frac{k_{ET}}{2}\left(T^2 - T_0^2\right)\right]$
		Germany	$1.2351 \cdot 10^{-4}$	
		EU	$2.943 \cdot 10^{-5}$	
Change in electricity production proportional to energy	k_E	Lithuania	$1.04 \cdot 10^{-1}$	$E = E_0 \exp\left[k_E\left(T - T_0\right)\right]$
		Germany	$2.49 \cdot 10^{-1}$	
		EU	$5.94 \cdot 10^{-02}$	
Change in electricity production proportional to time	k_T	Lithuania	7.05	$E = E_0 + \frac{k_T}{2}\left(T^2 - T_0^2\right)$
		Germany	$3.3 \cdot 10^{-02}$	
		EU	1.40	

For the EU, the GPESP growth trend is practically linear, although since 2018 deviations from the linear law have been observed, followed by a return to the trend. Overall, the development dynamics of GPESP in the EU are well described by the first and second models.

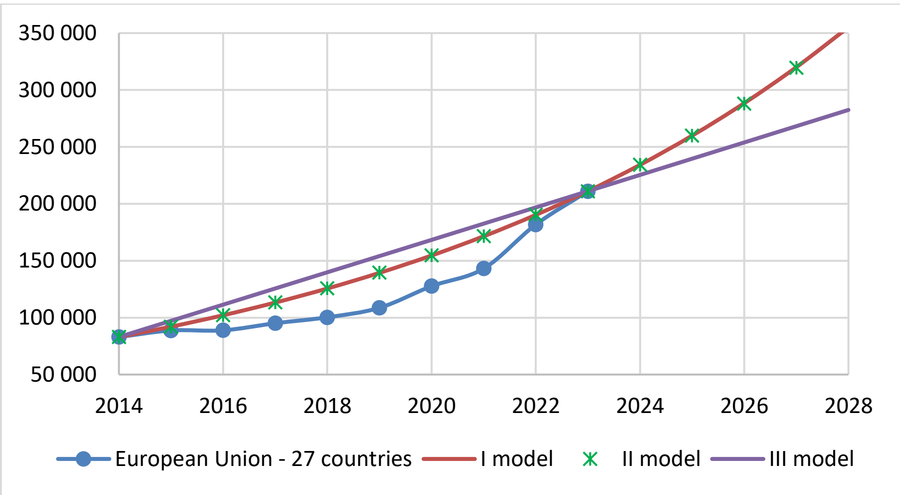

Figure 1. GPESP for EU countries, Gigawatt-hour.

The statistical analysis showed that during the period from 2014 to 2025, the total production of electricity from photovoltaic power plants (GPESP) in the European Union increased by 176.9 thousand GWh, or by a factor of 3.13. Such dynamics indicate an active phase of solar generation development, driven by the European Green Deal policy, financial incentives, and decreasing costs of photovoltaic systems. The further forecast for 2025–2028 demonstrates an expected increase of another 95.3 thousand GWh, or by 36.7%. This indicates the continuation of the upward trend, but with a gradual slowdown in growth rates, typical for markets transitioning from exponential growth to a more stable development stage. Thus, the dynamics of GPESP in the EU confirm its key role in achieving the strategic goals of increasing the share of renewables in the overall energy balance by 2030.

For Lithuania, the growth dynamics of GPESP are characterized by a sharp increase after 2020. The development dynamics of GPESP in Lithuania are also sufficiently well described by the first and second models.

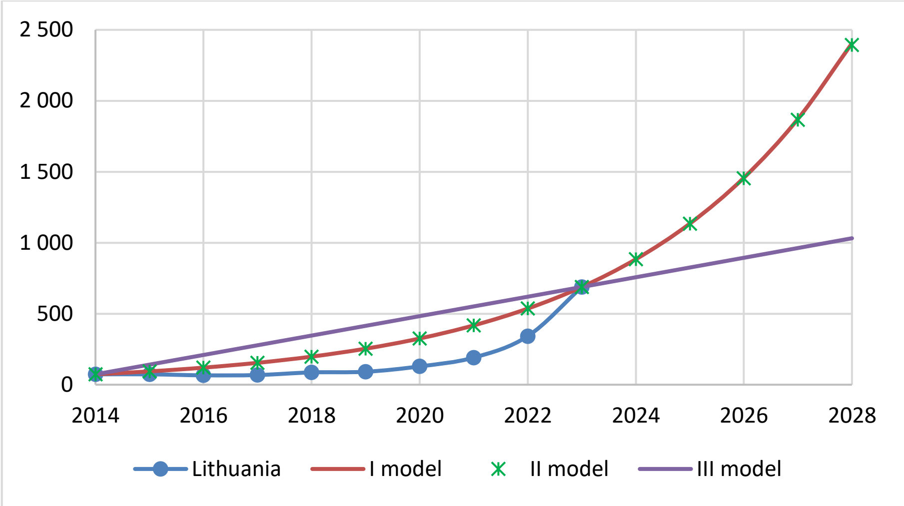

Figure 2. GPESP for Lithuania, Gigawatt-hour.

In Lithuania, solar energy shows exceptionally high growth rates. During 2014–2025, electricity production from photovoltaic plants increased by 1062 GWh, corresponding to a 15.55-fold increase. This surge was driven by government incentives for prosumers and active support for decentralized generation. The forecast for 2025–2028 indicates a further increase of 1270 GWh, or by a factor of 2.21, confirming the continuation of exponential growth. This highlights the strategic importance of solar energy for the country's energy independence and its contribution to achieving the European climate goals by 2030.

For Germany, the GPESP growth trend is practically linear, although with minor continuous fluctuations. The dynamics of GPESP development in Germany are also generally well described by the first and second models.

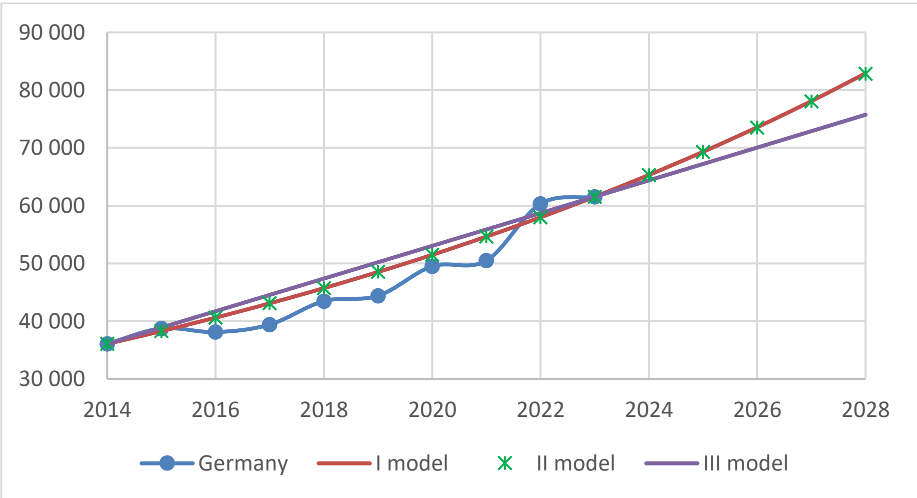

Figure 3. GPESP for Germany, Gigawatt-hour.

In Germany, solar energy shows stable growth. Between 2014 and 2025, the production of electricity from photovoltaic power plants increased by 33.3 thousand GWh, representing a 92.3% growth. The significant volume of GPESP confirms Germany's leading role among EU countries in solar generation, where the market is already at a mature stage characterized by steady expansion. The forecast for 2025–2028 indicates an additional increase of 13.6 thousand GWh, or 19.6%, reflecting a transition to a saturation phase. Thus, Germany's solar energy sector serves as an example of stable renewable energy integration into the national energy balance and confirms the country's ability to maintain leadership in the EU energy transition.

The results obtained confirm the key role of solar energy in achieving the EU's strategic goals in the fields of decarbonization and energy security. Although the European Union as a whole demonstrates stable growth in electricity production from photovoltaic power plants, the nature of this development differs by country. Lithuania, due to policies supporting prosumers and decentralized generation, has shown exponential growth rates (Elsun, 2024), while Germany is characterized by more gradual and stable capacity expansion (Eurostat, 2024). This confirms that the initial state of energy systems and regulatory approaches determine the trajectory of renewable energy development (Arias, Feijoo, & Moreira, 2023).

An important aspect is that the forecast for 2025–2028 indicates a slowdown in growth rates in the EU overall, and particularly in Germany. This may suggest the approach of a "saturation point" in the market, when further expansion will require not only technical solutions but also new economic incentives, the integration of energy storage systems, and the development of smart grids (IRENA, 2024a; IEA, 2023). By contrast, Lithuania is expected to maintain exponential dynamics, reflecting the potential of countries that are only beginning their large-scale transition to solar generation (APVA, 2024).

From a strategic perspective, it is important to emphasize the role of political and financial mechanisms. The development of energy communities, subsidies for energy storage, and investments in infrastructure play no less significant a role than technological progress in the field of photovoltaics (European Commission, 2019). This is confirmed by modeling results: scenarios that combine technological development with political support turned out to be the most optimistic in terms of solar generation growth (Mandys, Chitnis, & Silva, 2023).

Additionally, the global context should be considered. According to IEA forecasts, solar energy will become the leading renewable energy source in the world by 2029 (IEA, 2023). This means that EU countries have the opportunity to maintain leadership in the energy transition only if policies are coordinated, research investments are increased, and innovative business models (such as energy cooperatives or peer-to-peer electricity trading) are implemented (Obaideen et al., 2021; Saha, 2024).

Thus, the results of this study not only confirm the forecasts of international organizations but also provide additional arguments for the formation of national strategies. For the Baltic region countries, particularly Lithuania, the development of solar generation is critically important in view of energy independence after disconnection from the BRELL system (Elsun, 2024). For Germany, the challenges lie in maintaining steady growth in a mature market and integrating new technological solutions. In a broader perspective, the development of solar energy in the EU demonstrates that achieving the Green Deal targets is possible only through the synergy of technical, economic, and political factors (European Commission, 2019; IRENA, 2024b).

CONCLUSIONS

Solar energy plays a key role in the transformation of the EU energy sector. Statistical analysis revealed a significant increase in electricity production from photovoltaic power plants (GPESP) during 2014–2025:

for the EU – by 176.9 thousand GWh (a 3.13-fold increase);

for Lithuania – by 1062 GWh (a 15.55-fold increase);

for Germany – by 33.3 thousand GWh (a 92.3% increase).

Forecast calculations indicate further growth in production for 2025–2028, although the growth rate is gradually slowing down:

in the EU – an expected increase of 95.3 thousand GWh (36.7%);

in Lithuania – an increase of 1270 GWh (a 2.11-fold increase);

in Germany – an increase of 13.6 thousand GWh (19.6%).

The mathematical models applied in the study adequately describe the dynamics of solar generation development. The most accurate model proved to be the one that accounts for the proportionality of production growth to the volume of generated energy, confirming the effect of "cumulative dynamics."

The development of solar energy in the EU has different characteristics:

in Lithuania, exponential growth is observed, driven by policies stimulating prosumers and decentralized generation after disconnection from the BRELL system;

in Germany, the dynamics are more linear and stable, reflecting a phase of market maturity;

at the EU scale, the overall growth trend shows a transition from rapid development to a more balanced phase.

The practical significance of the results lies in the possibility of using the developed models to forecast the development of solar generation in EU countries and to justify investment volumes in renewable energy.

Strategic conclusion: solar energy can make a significant contribution to achieving the goals of the European Green Deal and the Energy Security Strategy by 2030, as well as to supporting decarbonization and the energy independence of EU member states.

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