

IMPLEMENTATION PROFILE OF SOLAR ENERGY SOLUTIONS THROUGH EU FUNDED ENERGY PROJECTS

Eliza Elza Lipsane, Gunita Mazure

Latvia University of Life Sciences and Technologies, Latvia
eliizaeza@gmail.com, gunita.mazure@lbtu.lv

Abstract. The rapid expansion of solar energy in Latvia in recent years is reflected in a significant increase in electricity generation. Annual electricity production from solar installations has increased from 5 GWh in 2020 to 536 GWh in 2024, reaching a cumulative output of 862 GWh over the period. This development provides an important context for examining the implementation of solar energy solutions through energy projects supported under the European Union programming period 2021-2027. The study aims to examine the implementation profile of solar energy solutions within a dataset consisting exclusively of the EU funded energy projects. The research employs keyword-based project identification and analysis of project metadata to extract projects related to solar energy. These projects are analysed in relation to the applicants implementing them, the stated project objectives, the funding amounts and whether solar energy constitutes the sole aim of the project or is combined with other objectives such as energy efficiency, building renovation or environmental improvements. The study demonstrates that the structure and description of solar energy projects within the dataset reveal important characteristics of this technology at the project level. Examination of these structural features provides insight into typical project profiles, the diversity of participants and the role of funding instruments in supporting the practical introduction of solar energy solutions. The analysed projects with solar energy as the primary objective generate 3026.46 MWh of electricity annually and reduce CO₂ emissions by 318.52 tonnes. A very strong positive correlation ($r = 0.998$) indicates a close relationship between energy production and emission reduction.

Keywords: solar energy, EU-funded projects, project implementation, energy projects.

Introduction

The transition towards renewable energy sources has become a key priority within the European Union's energy and climate policy framework. Increasing the share of renewable energy in electricity production is widely recognised as an important step to reduce greenhouse gas emissions, strengthening energy security and supporting long-term sustainable development [1]. Among the available renewable energy technologies, solar energy has experienced particularly rapid growth during the last decade due to technological improvements, falling installation costs and the availability of various support mechanisms [2; 3]. In Latvia, the development of solar energy has accelerated significantly in recent years. The number of installations has increased rapidly, which has been reflected in a sharp rise in electricity generation from solar sources. Annual solar electricity production increased from 5 GWh in 2020 to 536 GWh in 2024, demonstrating the speed at which this technology has been adopted within the national energy system [4]. In this context, the European Union (EU) funding programmes represent an important mechanism for supporting the practical implementation of renewable energy technologies, including solar energy solutions.

Financial support provided through the EU structural and investment funds represents one of the key mechanisms promoting renewable energy development in Latvia. During the EU programming period 2021-2027, a range of energy-related projects has been supported, including initiatives aimed at improving energy efficiency, modernising infrastructure and promoting environmentally sustainable solutions. In many cases, solar energy installations are implemented not only as standalone projects but also as part of broader development initiatives that combine renewable energy with other objectives, such as building renovation, infrastructure development or environmental improvements [5; 6]. Two of the funds that support projects related to solar energy are the European Regional Development Fund (ERDF) and the Just Transition Fund (JTF). The ERDF is a key component of the EU cohesion policy aimed at strengthening economic and social cohesion across EU regions. It provides financial support for initiatives that enhance regional competitiveness and sustainable development. Projects financed through this fund contribute to reducing regional disparities and promote balanced economic growth within the EU [7]. The JTF provides financial support to regions facing challenges related to the transition toward a climate-neutral economy by funding projects that encourage sustainable economic restructuring. Through these investments, the JTF helps mitigate the socio-economic effects of the green transition while promoting long-term sustainable development [8]. Both of these funding instruments

support the implementation of solar energy projects, while contributing to sustainable regional development in the EU.

While renewable energy development is often analysed at the national or sectoral level, less attention has been paid to the characteristics of renewable energy implementation at the project level. Examining individual projects supported through public funding programmes can provide valuable insight into how solar energy technologies are integrated into practical development activities, which types of organisations implement such projects and how project objectives are formulated in practice.

The aim of this study is thus to examine the implementation profile of solar energy solutions within a dataset consisting exclusively of the EU funded energy projects during the programming period 2021-2027. Particular attention is given to identifying projects that include solar energy components and analysing their key characteristics, including project objectives, applicant types and funding amounts. The analysis also distinguishes between projects where solar energy constitutes the primary project objective and those where it is implemented as part of a broader set of development activities.

Materials and methods

The analysis is based on a dataset of projects supported within the EU programming period 2021-2027 in Latvia [5]. The dataset contains project metadata including project titles, descriptions, goals, applicant information, sector classification according to NACE codes and the total project costs. The focus of the study is on projects that include solar energy solutions within their planned activities.

To identify relevant projects, a search was conducted in the “ES fondu projektu HP rādītāji” (EU Fund Project HP Indicators) dataset [6] using the pre-assigned category “Atjaunojamie energoresursi: saule” (Renewable energy resources: solar). Projects labelled with this category were selected for further analysis and their full descriptions were subsequently extracted from the “ES fondu projektu saraksts” (List of EU-funded Projects) dataset [5] using the project numbers. Following the initial selection, the identified and extracted projects were reviewed manually to verify their relevance to solar energy implementation. Particular focus was placed on the role of solar energy within the overall project objectives. Based on this assessment, the projects were divided into two groups. The first group includes projects where solar energy does not represent the main objective but appears as a supporting component within broader development activities. The second group consists of projects in which the implementation of solar energy solutions represents the primary project objective.

In addition to this classification, several project characteristics were examined. These include the economic sector of the project based on NACE classification, the type of applicant implementing the project and the total project cost. The analysis is primarily descriptive and aims to identify typical patterns in the way solar energy solutions are incorporated into the EU-funded projects. To examine the relationships between key variables (annual electricity generation, CO₂ emission reduction and project cost), a Pearson correlation analysis was performed using IBM SPSS Statistics software.

Results and discussion

Following the identification and classification of projects that include solar energy components, the analysed projects were grouped according to the role of solar energy within their objectives. This distinction makes it possible to examine how solar energy solutions are incorporated into the EU-funded projects and to identify common patterns in project design and implementation.

The projects were divided into two main groups:

- Group 1 consists of projects where solar energy does not represent the primary objective but is included as an additional component within broader development activities;
- Group 2 includes projects where the development or installation of solar energy solutions represents the main objective of the project.

The characteristics of the projects are presented in Table 1 and Table 2. These tables summarise key project attributes, including the sector of economic activity according to the NACE classification, the type of applicant implementing the project and the total project cost. Examining these characteristics provides an overview of the contexts in which solar energy technologies are integrated into broader development initiatives.

Table 1

Projects in which solar energy is not the main project objective (Group 1)

Project number	Project classification NACE	Project submitter	Total cost, EUR
6.1.1.3/1/24/A/011	42.11	Municipality	3 571 905.71
6.1.1.3/1/24/A/006	42.11	Municipality	1 411 764.71
6.1.1.3/1/24/A/003	42.11	Municipality	2 486 556.56
6.1.1.3/1/24/A/004	42.11	Municipality	3 196 853.47
6.1.1.3/1/24/A/017	42.11	Municipality	3 734 907.50
6.1.1.3/1/25/A/021	42.11	Municipality	2 480 629.97
6.1.1.3/1/25/A/020	42.11	Municipality	494 117.65
6.1.1.3/1/24/A/015	42.11	Municipality	1 773 262.32
6.1.1.3/1/24/A/013	42.11	Municipality	2 848 068.96
6.1.1.3/1/24/A/010	42.11	Municipality	2 011 616.49
6.1.1.3/1/24/A/016	42.11	Municipality	1 937 155.58
6.1.1.3/1/24/A/014	42.11	Municipality	2 057 340.68
6.1.1.3/1/24/A/005	42.11	Municipality	1 150 798.59
6.1.1.3/1/24/A/001	42.11	Municipality	852 280.46
6.1.1.3/1/24/A/012	42.11	Municipality	297 248.58
6.1.1.3/1/24/A/007	42.11	Municipality	3 044 702.86
6.1.1.3/1/24/A/002	42.11	Municipality	4 666 305.91
6.1.1.3/1/24/A/009	42.11	Municipality	2 941 140.01
6.1.1.3/1/25/A/023	42.11	Derived Public Person	5 341 059.81
6.1.1.3/1/24/A/008	42.99	Municipality	5 928 042.97

The data presented in Table 1 illustrate that solar energy installations in these projects are typically implemented as complementary solutions within wider infrastructure development initiatives. Nineteen of the twenty projects in this group are categorised under NACE 42.11 – Construction of roads and motorways and one is NACE 42.99 – Construction of other civil engineering projects n.e.c. The main goal for all of the projects in this group is to develop public infrastructure for business development. These projects are mostly implemented by municipalities, indicating that local governments have a significant role in integrating renewable energy technologies into public infrastructure development.

The distribution of municipalities involved does not point to a single dominant local authority. However, several municipalities, including Jelgava, Rēzekne, Preiļi and Alūksne, appear more than once, suggesting relatively higher levels of engagement. The projects are geographically distributed across several regions of Latvia, notably Vidzeme, Latgale, Kurzeme and Zemgale, while Riga region is not represented. This pattern suggests a stronger emphasis on regional development outside the capital area.

The total cost of projects in this group varies considerably, ranging from several hundred thousand euros to more than five million euros. For example, project No. 6.1.1.3/1/25/A/020 with the total cost of 297 248.58 EUR includes local improvements to the road infrastructure rather than large-scale construction. In comparison, project No. 6.1.1.3/1/24/A/008 with the total cost of 5 928 042.97 EUR involves the development of an industrial zone in Madona. The project includes the regeneration of a degraded industrial area and the construction of three hangar-type production buildings together with the surrounding infrastructure.

Project descriptions generally refer to the integration of sustainable or climate-neutral solutions within public infrastructure development. However, in most cases, these references remain general and do not specify the type, scale or capacity of the technologies applied. Only a limited number of projects identify concrete solutions, most notably charging infrastructure for electric vehicles. While solar energy could support a range of applications in urban infrastructure, such as solar-powered street lighting, traffic

monitoring systems and smart information displays [9; 10], its direct contribution within these projects cannot be clearly determined. As a result, it is not possible to quantify the share of solar energy in the overall project investments, suggesting that it is likely treated as a supplementary rather than a core component. All projects in this group are financed through the JTF, which provides support covering 85% of the total eligible project costs.

While the projects discussed above integrate solar energy as a complementary component within broader infrastructure development initiatives, in the second group of projects solar energy solutions represent the main objective of the investment. The main characteristics of these projects are presented in Table 2.

Table 2

Projects in which solar energy is the main project objective (Group 2)

Project number	Project classification NACE	Project submitter	Total cost, EUR
2.1.1.6/2/25/A/001	36.00	Private Limited Company	158 447.00
2.1.1.6/2/25/A/007	36.00	Private Limited Company	59 700.00
2.1.1.6/2/25/A/011	36.00	Private Limited Company	64 227.31
2.1.1.6/2/25/A/004	36.00	Private Limited Company	1 087 355.09
2.1.1.6/2/25/A/010	37.00	Private Limited Company	88 642.20
2.1.1.6/2/25/A/003	36.00	Private Limited Company	106 174.95
2.1.1.6/2/25/A/002	35.13	Private Limited Company	425 819.20
2.1.1.6/2/25/A/008	37.00	Private Limited Company	1 450 350.00
2.1.1.6/2/25/A/005	35.11	Private Limited Company	132 472.05
2.1.1.5/1/24/I/001	84.12	Direct state administration institution	16 121 138.00

Compared with the first group, these projects show greater diversity in terms of economic sectors and applicant types. The NACE classifications indicate that several projects are related to electricity production (35.11) and distribution (35.13) as well as to water collection, treatment and supply (36.00) and sewerage services (37.00). Although these projects fall under different NACE classifications, they share the same main objective – improving the energy efficiency of infrastructure used for public water supply services through the installation of solar energy systems.

All of these projects are implemented by private limited companies, highlighting the important role of private sector actors in the direct deployment of solar energy technologies. Project costs in this category also vary substantially. For example, project No 2.1.1.6/2/25/A/007 by “KULDĪGAS ŪDENS” with the total cost of EUR 59 700 includes the installation of a 100 kW solar panel park at Kuldīga water de-ironing station to reduce electricity consumption and increase the use of renewable energy in the water supply system. The installation will result in estimated annual reduction of 11.256 tonnes of CO₂ emissions. In comparison, project No 2.1.1.6/2/25/A/008 with the total cost of EUR 1 450 350 implemented by “Jūrmalas ūdens” includes the installation of a solar park expected to generate approximately 1,133.8 MWh of electricity annually, which would contribute to reducing CO₂ emissions by about 123.59 tonnes per year. These examples demonstrate the diverse scale of solar energy projects and their potential contribution to renewable electricity generation and greenhouse gas emission reduction. All of these projects are financed through the ERDF, which provides support covering 65% of the total eligible project costs.

A quantitative comparison of the key technical and environmental indicators of the selected projects is presented in Table 3. Missing values were estimated using average ratios derived from projects with complete data. Annual electricity generation was estimated based on the average electricity generation per installed kW (1.07 MWh per kW per year), while CO₂ emission reductions were estimated using the average CO₂ reduction per MWh generated (0.107 t CO₂·MWh⁻¹). This approach was chosen to ensure methodological consistency and comparability across the analysed projects. The estimated values are presented in italics.

Table 3

Technical and environmental indicators of selected projects

Project number	Installed capacity, kW	Annual electricity generation, MWh·year⁻¹	CO₂ emission reduction, t CO₂·year⁻¹
2.1.1.6/2/25/A/001	85	94.00	8.00
2.1.1.6/2/25/A/007	100	155.00	11.26
2.1.1.6/2/25/A/011	128	137.00	9.93
2.1.1.6/2/25/A/004	962	933.00	101.66
2.1.1.6/2/25/A/010	63	67.41	7.21
2.1.1.6/2/25/A/003	71	56.62	8.79
2.1.1.6/2/25/A/002	340	354.00	37.88
2.1.1.6/2/25/A/008	999	1 133.85	123.59
2.1.1.6/2/25/A/005	100	95.58	10.20
Total	X	3 026.46	318.52

In total, the projects generate 3 026.46 MWh of electricity annually and achieve a combined CO₂ emission reduction of 318.52 tonnes per year. The results highlight significant differences in project scale. The largest project, with an installed capacity of 999 kW produces 1 133.85 MWh annually and achieves the highest CO₂ emission reduction of 123.59 tonnes per year. In contrast, the smallest project, with a capacity of 63 kW, generates 67.41 MWh and reduces CO₂ emissions by 7.21 tonnes annually. Despite these differences, a clear pattern can be observed: higher electricity generation is associated with greater CO₂ emission reductions. To further examine this relationship, a correlation analysis was performed.

The Pearson correlation analysis reveals an extremely strong positive relationship between annual electricity generation and CO₂ emission reduction ($r = 0.998$, $p < 0.001$), indicating that higher levels of renewable energy production are almost perfectly associated with greater emission reductions. This is consistent with expectations, as renewable electricity directly replaces fossil-based energy sources. Additionally, the analysis shows a very strong positive correlation between total project cost and annual electricity generation ($r = 0.992$, $p < 0.001$), suggesting that larger investments are closely linked to higher energy output due to increased installed capacity.

Together, these findings demonstrate a consistent relationship across all key variables: higher investments lead to higher energy production, which in turn results in greater CO₂ emission reductions. Overall, the analysis confirms that investment in solar energy infrastructure has a direct and measurable impact on both energy generation and environmental performance.

Although the present study does not include predictive modelling of future solar energy development, the identified patterns provide indications of potential trends beyond 2027. The strong relationship observed between project investment, electricity generation and CO₂ emission reduction suggests that continued financial support through EU funding instruments may lead to further expansion of solar energy capacity. In addition, the increasing involvement of the private sector and the integration of solar solutions across different sectors indicate a growing diversification of solar energy applications. These tendencies suggest a high likelihood that solar energy development within the EU-funded projects in Latvia will continue to expand, both through dedicated renewable energy projects and through integration into broader infrastructure and development initiatives. This is supported by the European Union climate and energy policy objectives [11] aimed at increasing the share of renewable energy to at least 42.5% by 2030 and advancing the transition towards a climate-neutral economy.

The project No 2.1.1.5/1/24/I/001 was not included in the quantitative comparison table. It is classified under NACE 84.12 – Regulation of the activities of providing health care, education, cultural services and other social services, excluding social security. It is implemented by the direct state administration institution “Valsts izglītības attīstības aģentūra” with a total cost of EUR 16 121.138. The main goal of this project is to improve the energy efficiency of vocational education institutions through the introduction of climate-neutral infrastructure solutions.

An important component is the integration of renewable energy technologies, including solar energy, together with smart energy management and monitoring systems. The project covers 23 state vocational education institutions, where the implemented technologies are intended not only to improve the energy performance of educational buildings but also to serve as a practical learning environment. By integrating renewable energy solutions into the educational infrastructure, students gain opportunities to develop knowledge and practical skills related to sustainable energy technologies, energy management and environmentally responsible practices. This project is financed through the ERDF, which provides support covering 85% of the total eligible project costs. However, it differs significantly from the other analysed projects, as it represents a large-scale, multi-institutional programme rather than a single-site renewable energy installation. The key quantitative indicators are either not explicitly defined or aggregated, making direct comparison difficult. Therefore, the project was excluded from the table to ensure methodological consistency.

To provide a clearer overview of the differences between the two groups, the main characteristics of the analysed projects are summarised in Table 4.

Table 4

Group 1 and Group 2 key characteristics

Group 1 – Solar energy not primary objective	Group 2 – Solar energy primary objective
<ul style="list-style-type: none"> • Solar energy used as complementary solution; • Mainly municipality-implemented projects; • NACE mostly 42.11 – Construction of roads and motorways; • Focus on public infrastructure for business development; • Integrated solar energy solutions within public infrastructure; • Funded by the Just Transition Fund (85% support). 	<ul style="list-style-type: none"> • Direct installation of solar energy systems; • Mainly implemented by private limited companies; • Sectors include education, water supply and sewerage services; • Aim to increase renewable energy generation and energy efficiency; • Expected outcomes include CO₂ emission reduction; • Funded through the ERDF (65% and 85% support).

The comparison of the two groups demonstrates that solar energy technologies can be implemented through different development approaches. While some projects focus on large-scale solar installations as the primary investment objective, others integrate smaller solar energy solutions within broader infrastructure projects. This indicates that the expansion of solar energy does not rely solely on dedicated renewable energy projects but can also be effectively supported through the integration of solar technologies into wider development initiatives.

To further interpret these findings, a comparison with other Baltic countries is provided. Studies from Lithuania indicate that the implementation of solar energy within publicly supported projects is influenced not only by financial support mechanisms but also by administrative capacity and public acceptance, which can affect the effectiveness of project implementation [12; 13]. This suggests that differences across countries are shaped not only by funding availability but also by institutional and social factors. The results of this study show that, within the EU-funded projects in Latvia, solar energy solutions are primarily implemented through structured, project-based mechanisms and are often integrated into broader infrastructure development activities. Compared with Lithuania, where administrative and societal barriers have been identified, the Latvian case indicates a stronger reliance on EU funding instruments as a key driver of implementation. In Estonia, renewable energy development is more closely linked to long-term strategic planning and national policy frameworks [14], supporting a more coordinated expansion of renewable energy capacity. In contrast, the Latvian approach appears more decentralised and project-oriented, facilitating integration across sectors but limiting the scale of individual installations.

Overall, the comparison highlights distinct implementation approaches within the Baltic region. Project-based models support diversification and cross-sectoral integration, whereas strategy-driven approaches may enable larger-scale and more coordinated development. The findings suggest that,

within the EU-funded projects, Latvia demonstrates a distinct implementation profile characterised by strong reliance on funding instruments and integrated project design.

In addition to the factors discussed above, land use considerations represent an important dimension of solar energy implementation. The expansion of large-scale solar parks may lead to competition for land resources, particularly when agricultural land is converted for energy production. Previous studies have identified land-use conflicts as a relevant challenge in renewable energy development, highlighting economic and spatial trade-offs associated with the conversion of agricultural land [15]. At the same time, recent studies emphasise that these conflicts can be mitigated through integrated land-use approaches, such as agrivoltaic systems, where solar energy production is combined with agricultural activities [16]. These approaches enable more efficient use of land and support the coexistence of energy production and agricultural systems. In the context of the projects analysed in this study, such land-use conflicts appear to be limited within the analysed projects. The solar energy systems included in Table 3 are primarily installed within the territories owned or managed by private limited companies providing public water supply and sewerage services. These installations are typically located near existing infrastructure, such as water treatment facilities and pumping stations, rather than on agricultural land. This suggests that within the analysed EU-funded projects, solar energy deployment is largely based on the utilisation of already developed or functionally designated areas, thereby reducing potential competition with agricultural land use.

Conclusions

1. The EU-funded projects that include solar energy solutions can be divided into two groups: projects where solar energy represents the main objective and projects where it is implemented as a complementary component within broader development activities.
2. Group 1 projects are predominantly implemented by municipalities and focus on infrastructure development, particularly road construction and other civil engineering activities, where solar energy is integrated as a supplementary component and its scale and contribution cannot be quantitatively assessed based on the available project data.
3. Group 2 projects are implemented by a more diverse group of applicants, including private companies and public institutions, and are related to sectors such as education, water supply and sewerage services.
4. Group 2 projects include solar energy installations, with installed capacity ranging from 63 kW to 999 kW, resulting in a total annual electricity generation of 3,026.46 MWh and a combined CO₂ emission reduction of 318.52 tonnes per year.
5. A very strong positive correlation was identified between annual electricity generation and CO₂ emission reduction ($r = 0.998$, $p < 0.001$), as well as between total project cost and annual electricity generation ($r = 0.992$, $p < 0.001$), confirming that higher investment levels are directly associated with increased electricity generation and, consequently, greater CO₂ emission reductions.
6. The results show that the EU funding instruments support both direct investments in solar energy technologies and the integration of solar energy solutions within broader infrastructure and development projects.
7. The findings indicate that within the EU-funded projects in Latvia, solar energy development is primarily driven by project-based funding mechanisms and integrated infrastructure approaches, while potential conflicts with agricultural land use remain limited due to the location of installations within existing infrastructure areas.

Author contributions:

Conceptualization, E.E.L.; methodology, E.E.L. and G.M.; software, E.E.L.; investigation, E.E.L.; data curation, E.E.L.; writing - original draft preparation, E.E.L.; writing - review and editing, G.M. and E.E.L.; project administration, E.E.L. and G.M. All authors have read and agreed to the published version of the manuscript.

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