INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

Publisher
Sustainability for Regions

TECHNICAL AND ECONOMIC EVALUATION OF PHOTOVOLTAIC PANELS: A CASE STUDY BASED ON INTERDISPCIPLINARY APPROACH*

Chaymae Taib [1*], Zineb Aqachmar [2], Najiba El Amrani El Idrissi [3], Manuela Tvaronaviciene [4]

[1,3] Faculty of Science and Technology, Sidi Mohamed Ben Abdellah University, Route d'Imouzzer 30000 Fez, Morocco
[2] Faculty of Science, Cadi Ayyad University, Bd Abdelkrim Al Khattabi, 40000 Marrakech, Morocco*
[4] Faculty of Business Management, Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius, Lithuania

E-mails: [1]chaymae.taib@usmba.ac.ma (Corresponding author); [2] zineb.aqachmar@uca.ac.ma; [3]najiba.elamrani@usmba.ac.ma; [4]manuela.tvaronaviciene@vilniustech.lt*

Received 18 May 2025; accepted 22 August 2025; published 30 September 2025

Abstract. This study evaluates the performance of SoliTek SOLID B.60 bifacial photovoltaic panels in four Lithuanian cities; Vilnius, Klaipėda, Telšiai, and Dotnuva, each representing a distinct climate zone as defined in national classifications. Using the System Advisor Model (SAM) and standardized 2022 weather data from NSRDB, the same technical system and a merchant plant financial model were applied across all cities/ to ensure comparability. Key performance indicators; energy output, capacity factor, levelized cost of energy (LCOE), and Net Present Value (NPV) were analyzed. Results show Klaipėda outperforms other cities in both technical and financial metrics, while Vilnius yielded the lowest performance. The study highlights the advantage of using locally manufactured panels and consistent simulation parameters for realistic assessment. Use of interdisciplinary evaluation approach allows to take into account main technical panels' performace indicators together with economic attractiveness. This approach is especially promising in the context of increasing global competition in the area of photovoltaic industry.

Keywords: photovoltaic; solar energy; performance indicators; System Advisor Model (SAM); climatic zones; interdisciplinary approach; technical evaluation; economic evaluation; Lithuania

Reference to this paper should be made as follows: Taib, Ch., Aqachmar, Z., El Amrani El Idrissi, N., Tvaronaviciene, M 2025. Technical and economic evaluation of photovoltaic panels: a case study based on interdispciplinary approach. *Insights into Regional Development*, 7(3), 123-136. http://doi.org/10.70132/p6943275885

JEL Classifications: O14, O32, O33

Additional disciplines: ecology and environment; electricity electronic engineering; environmental engineering; energetics and thermoenergetics

* *The research leading to these results has received funding from the project titled "Cluster for innovative energy" in the frame of the program "HORIZON-MSCA-2022-SE-01" under the Grant agreement number 101129820*

European Research Council
Established by the European Commission

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

1. Introduction

The global transition towards sustainable energy systems has intensified the focus on photovoltaic (PV) technologies, particularly in regions seeking to optimize local solar potential. In the European context, Lithuania presents a valuable case for PV deployment analysis due to its diverse climatic zones, increasing renewable energy targets, and the presence of local solar manufacturers like SoliTek. Previous research, such as the regional PV performance assessment conducted in Morocco (Aqachmar et al., 2020), demonstrated the importance of evaluating solar installations across varying climate conditions. Inspired by that methodology, this study investigates the performance of the SoliTek SOLID B.60 Bifacial 370W photovoltaic module across four representative Lithuanian cities; Vilnius, Klaipėda, Telšiai, and Dotnuva, each located within a distinct climatic zone identified in Lithuanian climatological studies (Akstinas, 2017).

Using the System Advisor Model (SAM) (*About - System Advisor Model - SAM*, n.d.), a simulation-based software developed by the U.S. National Renewable Energy Laboratory (NREL), we applied a consistent technical configuration and a European merchant plant financial model to assess system viability. By standardizing system parameters and using 2022 Typical Meteorological Year (TMY) data from the NSRDB database (*NSRDB*, n.d.), this study aims to ensure comparability of results across all locations.

The objective of this paper is to compare photovoltaic performance across Lithuania's key climate zones using real climate data, while emphasizing the benefits of using locally manufactured PV panels. The study also aims to identify the most suitable zones for deployment and provide initial insights for future use of storage systems or net-zero energy solutions

2. Literature review

The deployment and performance assessment of photovoltaic (PV) systems have been widely studied to support renewable energy planning across various climates (Paiano et al., 2023; Tyagi & Kumar, 2024; Zhou et al., 2024)

In Morocco, a study by (Aqachmar et al. 2020) compared PV performance across different climatic regions using simulations to identify optimal zones for solar energy deployment. This approach inspired the current study, emphasizing how geographical and meteorological diversity can affect solar output. The study focused on high-concentration PV plants across six climatic zones in Morocco, demonstrating significant variations in energy yield, capacity factor, and LCOE depending on location. (Ayompe et al. 2010) evaluated the performance of a grid-connected PV system under Irish climate conditions, emphasizing the importance of using accurate local weather data in simulation tools to obtain realistic estimates. Similarly, (Erdinc, Paterakis & Catalaõ 2015) performed a techno-economic analysis of PV systems in different regions of Turkey and identified how regional differences in irradiance and temperature impact the feasibility of solar deployment. Recent studies further highlight diverse PV applications: (Aktas & Ozenc 2024) analyzed the techno-economic and environmental aspects of a grid-connected college rooftop system, (Neama & Alfahed 2024) assessed residential-scale PV in Iraq, and (Zhang et al. 2025) evaluated community-level BIPV systems, showing both aesthetic and environmental benefits. Together, these studies underline how context-specific factors influence the viability and design of PV systems.

Lithuania also shows climate variation across its territory, and (Akstinas, 2017) provided a detailed classification into four climate zones. The System Advisor Model (SAM) by NREL is frequently used in simulation-based PV research. (De Soto et al., 2006) validated models of irradiance and temperature in SAM, while (Blair et al., 2014) offer comprehensive documentation of its technical and financial simulation capabilities. In 2023, (Ayadi et al., 2024) used SAM (version 2023.12.17) to evaluate a 100 MW utility-scale bifacial PV plant in six desert regions, revealing low LCOE and high capacity factors, highlighting SAM's utility across climates. Recent work by (Badran & Dhimish,

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

2024) also supports bifacial system use in temperate climates, showing 7 to 10% increased energy gain. Another study by (Sun et al., 2018) emphasized that bifacial panels mounted vertically or elevated can significantly increase yield up to 30% depending on albedo and design.

Additionally, the role of locally manufactured PV panels has gained attention for both sustainability and energy security. According to IRENA (IRENA, 2022, 2023, 2025; IRENA Renewable Power Generation Cost, 2020; Renewable Energy Agency, 2024, 2025), localized production can enhance resilience to geopolitical tensions and reduce emissions associated with international logistics. Studies like those by (Kaldellis & Zafirakis, 2011) have also highlighted how using regional manufacturing capacities for renewable technologies strengthens national energy strategies.

3. Methodology

This study adopts a simulation-based approach using the System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL) to evaluate the performance of photovoltaic systems in different Lithuanian climate zones (see Figure 1). The methodology can be broken down into the following steps:

2.1. Selection of climatic zones and key cities

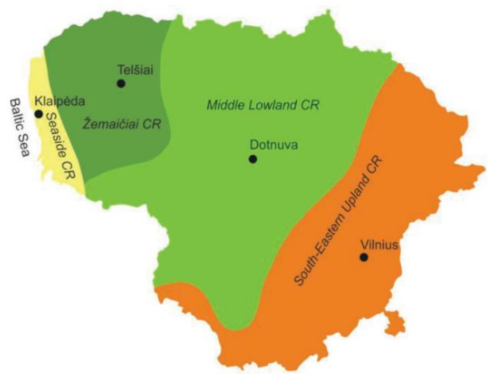

Figure 1. Climate regions of Lithuania and location of meteorological stations
Source: (Akstinas, 2017)

Based on the climatic zone classification proposed by (Akstinas, 2017) this study categorized the country into four principal climatic regions. For each zone, a representative city was selected based on population density and geographical centrality:

- Vilnius (Southeastern zone)
- Dotnuva (Central zone)
- Telšiai (Northwestern zone)
- Klaipėda (Coastal zone)

This zoning enabled a consistent comparative analysis of PV performance across distinct meteorological conditions.

2.2. Weather data acquisition

To ensure consistency and reliability in our simulations, we used Typical Meteorological Year (TMY) 2022 weather data from the National Solar Radiation Database (*NSRDB*, n.d.) managed by the National Renewable Energy Laboratory (NREL) in the United States. The NSRDB provides hourly weather data with high spatial resolution, based on information collected from satellites and weather stations, which helps maintain a consistent standard across all locations. For each of the four selected cities; Vilnius, Dotnuva, Telšiai, and Klaipėda, the following weather variables were used:

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

- Global Horizontal Irradiance (GHI) (Reno & Hansen, 2014)
- Direct Normal Irradiance (DNI) (Blanc et al., 2014)
- Ambient temperature
- Wind speed
- Relative humidity

By using data from the same source and selecting the same year for all cities, the approach ensures uniformity in weather inputs, enabling a fair and accurate comparison of PV system performance across different climatic regions.

2.3. PV module selection

The PV panel selected for the simulation was the SOLID B.60 Bifacial 370W by SoliTek, a local manufacturer based in Lithuania. The choice of this module was based on its local production, which aligns with European sustainability goals. Using locally produced panels not only reduces transportation-related emissions but also supports the regional economy. Additionally, the panel utilizes bifacial technology, allowing it to capture sunlight from both the front and rear sides, thereby enhancing system efficiency. This rear-side irradiation capability is particularly beneficial in highly reflective environments, such as those with snow-covered surfaces.

The module specifications were manually entered into SAM (System Advisor Model) based on its datasheet (Bifacial, n.d.). It has a nominal maximum power output of 370 W, with an efficiency of approximately 20%. The temperature coefficient is -0.32 %/°C, indicating the power loss with increasing temperature. The open circuit voltage (Voc) is 40.50 V, and the short circuit current (Isc) is 11.18 A. Under maximum power conditions, the panel operates at a voltage (Vmpp) of 34.86 V and a current (Impp) of 10.62 A. The panel uses bifacial cells (Guerrero-Lemus et al., 2016) and a glass-glass structure, which means it's made with glass on both sides to make it more efficient and durable.

2.4. PV system configuration in SAM

All simulations were conducted using System Advisor Model (SAM) version 2024.12.12. The system was configured using the "Photovoltaic → Detailed PV → Merchant Plant" model. This option was chosen because it allows for detailed technical and financial modeling of grid-connected PV systems, with flexible inputs options.

The configuration was based on the SOLID B.60 Bifacial 370W module and optimized for Lithuania's climate. To maintain consistency across all simulation sites, the following setup was used: 900 modules arranged as 30 modules per string with 30 strings in parallel resulting in a total DC capacity of 333.2 kWdc (900 × 370 W). The ground coverage ratio (GCR) was set to 0.45, ensuring realistic row spacing, as supported by (Ferry et al., 2025) for European installations. The modules were installed at a ground clearance of 1.5 meters. A fixed tilt angle of 30° was chosen to match Lithuania's latitude (~55°) (*GPS Coordinates of Lithuania. Latitude: 55.1736 Longitude: 23.8948*, n.d.) following the common practice in countries with climates similar to Lithuania, such as Poland (*What Is the Optimal Solar Panel Tilt Angle? Poland and the World - Electrum*, n.d.). The azimuth angle was set to 180°, meaning the panels were facing south to maximize solar exposure. The fixed tilt system was selected instead of a tracking system to reflect a cost-effective and low-maintenance solution, commonly used in Lithuania and similar climates (IRENA Renewable Power Generation Cost, 2020).

The economic configuration was based on the Merchant Plant model, where the plant sells electricity directly to the market. Financial estimates commonly used in Europe were applied, with an electricity sale price of 110 €/MWh as the market average, operation and maintenance costs set at 20 €/kW/year based on regional averages (IRENA Renewable Power Generation Cost, 2020), a discount rate of 6%, an inflation rate of 2%, and a project lifetime of 25 years. The financial model excludes subsidies and tax incentives to maintain a conservative and broadly applicable scenario.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

2.5. Performance indicators

To assess and compare the performance of photovoltaic systems across Lithuania's climate zones, four key performance indicators (KPIs) were selected. These indicators capture both the technical performance and economic feasibility of each simulated PV installation.

Annual energy yield (AEY)

The annual energy yield is the total amount of electrical energy generated by the PV system over a year under real-world conditions. It is expressed in kilowatt-hours (kWh).

Capacity Factor (CF)

The capacity factor (%) is the ratio of actual electricity generated over a period of time to the energy that would have been generated if the plant operated at full capacity during that time. A higher capacity factor indicates better system utilization.

Levelized Cost of Energy (LCOE)

LCOE (€/kWh) represents the average cost per unit of electricity generated, accounting for the total lifecycle costs (investment, operations, and maintenance) and electricity output (IRENA Renewable Power Generation Cost, 2020). A lower LCOE suggests a more economically attractive system.

Net Present Value (NPV)

NPV (€) evaluates the financial profitability of a project by comparing the present value of cash inflows to outflows over its lifetime. A positive NPV indicates that the project is financially viable.

These KPIs allow for a comparison of PV installations across cities, capturing both the energy efficiency (via the AEY and CF) and economic performance (via LCOE and NPV). By integrating these indicators, decision makers can better evaluate the suitability of PV projects under different climatic and financial conditions.

3. Results and discussion

This section presents and discusses the simulation results of the SOLID B.60 bifacial PV system deployed across four representative cities of Lithuania: Vilnius, Dotnuva, Telšiai, and Klaipėda. The analysis is centered on the technical performance, economic feasibility, and energy generation dynamics, drawing comparisons across regions using key performance indicators: Annual Energy Yield, Capacity Factor, Levelized Cost of Energy (LCOE), and Net Present Value (NPV).

3.1. Annual energy yield

The annual AC energy yield represents the total electricity delivered to the grid during the first operational year.

Table 1. Comparison of annual AC energy, energy yield, and performance ratio across the four cities

City	Annual AC energy (kwh)	Energy yield (kwh/kw)	Performance ratio
Vilnius	279,391	839	0.76
Dotnuva	291,555	875	0.76
Telšiai	286,451	860	0.75
Klaipėda	306,235	919	0.74

As shown in Table 1 above, Klaipėda achieved the highest energy production of approximately 306,235 kWh, followed by Dotnuva (291,555 kWh) and Telšiai (286,451 kWh). Vilnius had the lowest yield at 279,391 kWh. This result is consistent with Klaipėda's location in the coastal region, which benefits from higher solar irradiation and fewer extreme cold spells, enhancing photovoltaic conversion. In contrast, Vilnius, located inland with more

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

cloud cover and colder winters, recorded the lowest output, despite sharing the same PV configuration, highlighting the climatic variability across regions.

Performance ratios across all cities hovered between 0.74 and 0.76, indicating relatively stable system losses (e.g., from temperature, inverter inefficiencies, or soiling), with no region-specific anomalies. This supports the robustness of the bifacial module and system design across Lithuania's climatic diversity.

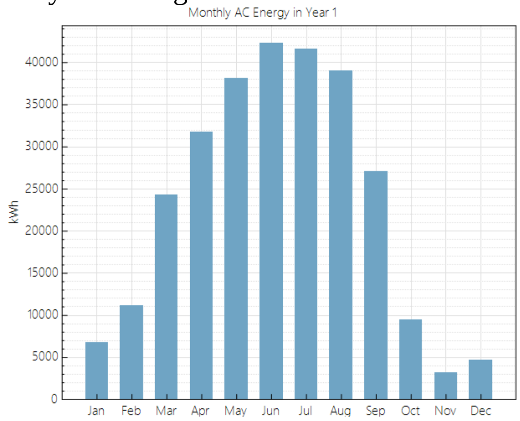

Figure 2. Monthly distribution of AC energy generation in year 1 - Vilnius

Figure 2 above illustrates the monthly AC energy production of the Vilnius installation during the first year. Peak generation occurs in June and July, while November shows the lowest output due to reduced irradiance and shorter daylight hours.

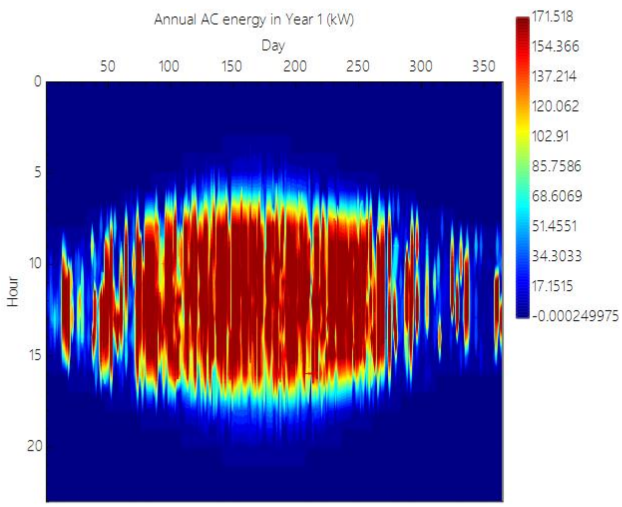

Figure 3. Annual hourly AC energy generation heatmap - Vilnius

The heatmap (Figure 3) reveals a pronounced concentration of energy production between 9:00 and 16:00 from April to August. The seasonal patterns align with expected solar availability in southeastern Lithuania.

Similarly, the central region city of Dotnuva exhibits a comparable but slightly reduced generation profile (see Figure 4 below).

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

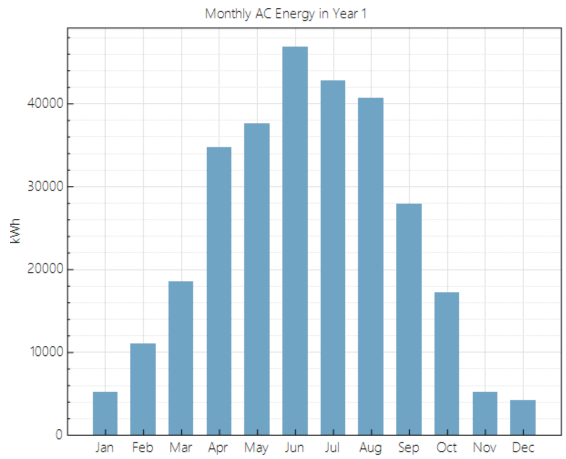

Figure 4. Monthly distribution of AC energy generation in year 1 - Dotnuva

Dotnuva's monthly production shows a similar seasonal pattern, with the highest output during summer months and a noticeable dip in winter. Overall, the energy yield remains relatively stable during spring and fall (Figure 5).

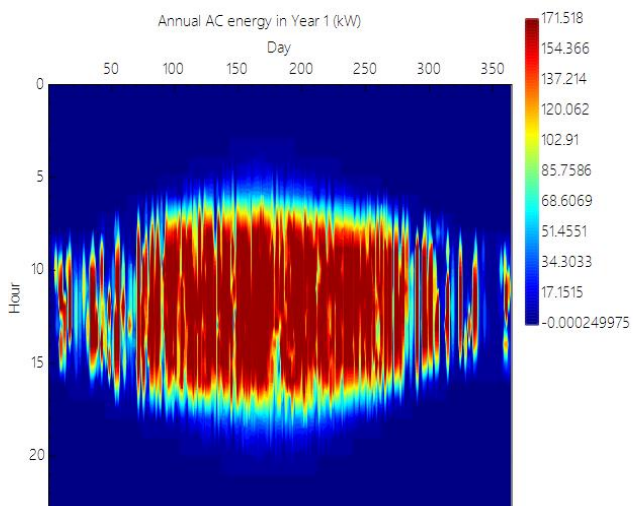

Figure 5. Annual hourly AC energy generation heatmap - Dotnuva

The heatmap for Dotnuva confirms steady performance during midday hours in summer, with a gradual ramp-up and decline around the peak months. Winter months show significantly limited energy production.

In the northwestern region, Telšiai’s energy profile is influenced by slightly lower irradiance and cooler temperatures (see Figure 6 below).

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

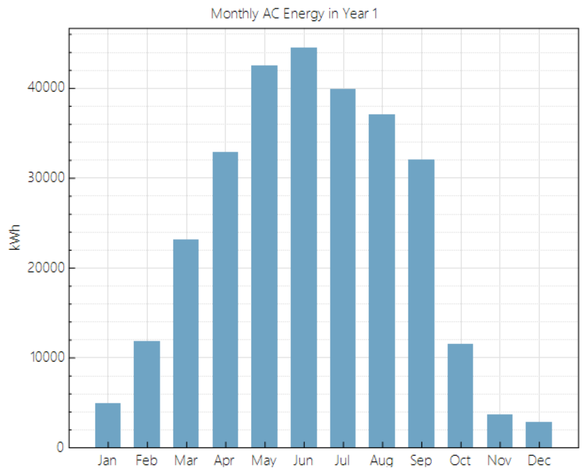

Figure 6. Monthly distribution of AC energy generation in year 1 - Telšiai

Monthly AC energy production in Telšiai mirrors the general seasonal pattern but with slightly lower summer peaks compared to Vilnius and Dotnuva (Figure 7). The winter production remains minimal, reflecting regional solar availability.

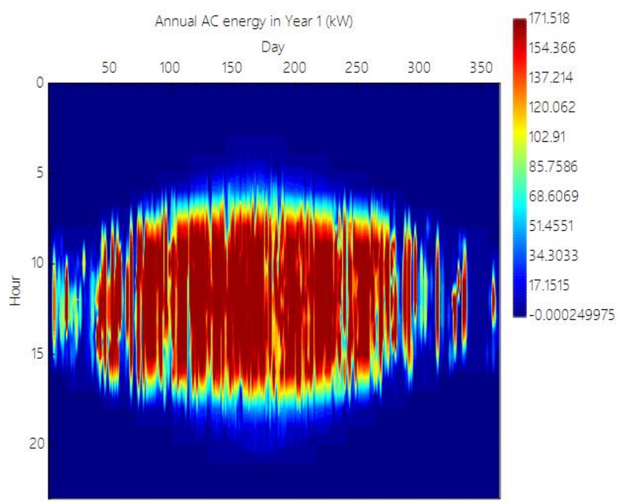

Figure 7. Annual hourly AC energy generation heatmap – Telšiai

The heatmap highlights consistent summer performance with limited variability, though daily generation appears slightly compressed compared to southern counterparts, possibly due to cloud cover or diffuse irradiance conditions.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

Finally, Klaipėda, representing the coastal region, shows a distinct generation pattern due to maritime influence (Figure 8).

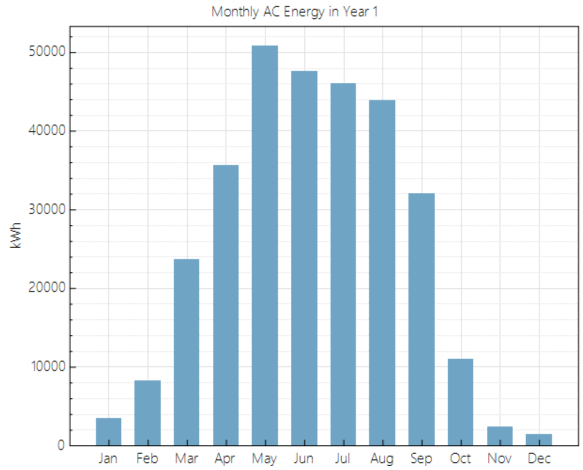

Figure 8. Monthly distribution of AC energy generation in year 1 - Klaipėda

Klaipėda's monthly energy yield demonstrates smoother transitions between months, with less pronounced seasonal extremes. This stability may be attributed to the moderating effects of the coastal climate.

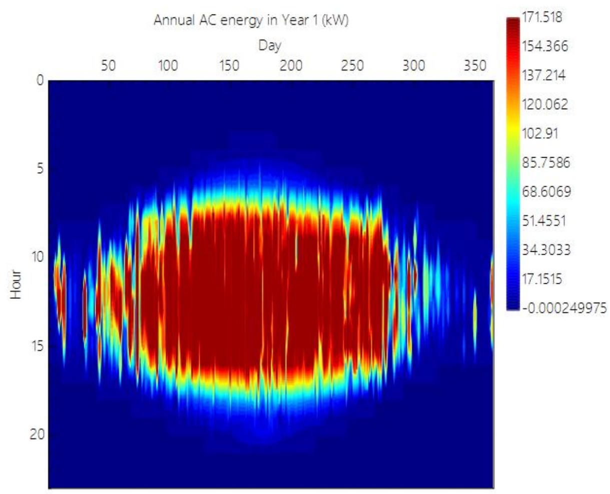

Figure 9. Annual hourly AC energy generation heatmap - Klaipėda

The generation heatmap for Klaipėda (Figure 9 above) reveals sustained midday production throughout much of the year, with slightly fewer sharp peaks compared to inland cities, indicating more diffuse radiation and consistent weather patterns.

3.2. Capacity factor

The DC capacity factor indicates how effectively each system operates compared to its maximum potential, showed slight regional variation in Table 2.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

Table 2. DC capacity factor of the PV system across different climatic zones of Lithuania

City	Capacity Factor (%)
Klaipėda	10.5
Dotnuva	10.0
Telšiai	9.8
Vilnius	9.6

Although values are relatively close, Klaipėda again led with the highest capacity factor, exceeding the 10% threshold, suggesting more favorable solar irradiance. The difference percentage points between Klaipėda and Vilnius is significant, especially in long-term energy projections. This confirms that location-specific solar availability directly impacts system effectiveness, even in a country with overall moderate solar resources.

3.3 Levelized Cost of Energy (LCOE)

The LCOE, representing the average cost of electricity produced over the system's lifetime, incorporates capital, O&M, and financial assumptions. Both nominal and real values are shown in Table 3 and Table 4 respectively.

Table 3. Levelized cost of energy (LCOE) - nominal - in Vilnius, Dotnuva, Telšiai, and Klaipėda

City	LCOE nominal (€/kWh)
Klaipėda	11.47
Dotnuva	11.90
Telšiai	12.05
Vilnius	12.28

Table 4. Levelized cost of energy (LCOE) - real - in Vilnius, Dotnuva, Telšiai, and Klaipėda

City	LCOE real (€/kWh)
Klaipėda	9.29
Dotnuva	9,64
Telšiai	9.76
Vilnius	9.95

Again, Klaipėda stands out with the lowest LCOE, demonstrating higher economic efficiency. This is driven mainly by its superior energy yield, which spreads the investment and operational costs over more kilowatt-hours, thereby reducing the average cost per unit. The financial benefit becomes more evident when combined with the net present value.

3.4. Net Present Value (NPV)

NPV evaluates the overall profitability of the system by taking into account future cash flows discounted over time.

Table 5. Financial Profitability Metrics: Net Present Value (NPV)

City	NPV ($)
Vilnius	64,204
Dotnuva	86,038
Telšiai	78,432
Klaipėda	102,768

The NPV results clearly highlight that Klaipėda is the most profitable location for PV deployment in Lithuania (see Table 5 above). Dotnuva follows closely, suggesting that central regions may also offer economically viable opportunities for solar projects. Vilnius, despite being a major urban center, yielded the lowest NPV due to its relatively lower energy yield.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2025 Volume 7 Number 3 (September)
http://doi.org/10.70132/p6943275885

Interpretation

Klaipėda shows the most favorable combination of technical and financial performance. Its coastal conditions, higher irradiance, and fewer extreme winters result in better PV system efficiency and lower costs. Dotnuva and Telšiai perform well technically and economically, supporting the idea that central and northwestern regions are suitable for solar deployment. Vilnius, while showing the lowest figures, still meets acceptable performance standards, confirming the nationwide viability of PV technology.

Conclusions

This study evaluated the performance of a locally produced bifacial photovoltaic module across four representative Lithuanian cities; Vilnius, Dotnuva, Telšiai, and Klaipėda, each corresponding to a distinct climatic zone. Using the system advisor model (SAM) and standardized TMY weather data from the NSRDB, we conducted a uniform simulation and financial analysis to assess key performance indicators, including annual energy yield, capacity factor, LCOE, and NPV.

The results show that although Lithuania has a relatively homogenous climate, regional variations affect photovoltaic performance. Klaipėda demonstrated slightly higher energy outputs and financial returns, attributed to better irradiation and lower system losses. Despite these differences, all zones exhibited strong potential for PV deployment, particularly with the SoliTek SOLID B.60 bifacial module, which proved well-adapted to local conditions.

These findings highlight the value of regionalized energy planning and emphasize the importance of using locally manufactured modules in Lithuania's PV strategies. Beyond the Lithuanian context, this research framework can be adapted to evaluate alternative PV technologies under the same climatic and financial scenarios. Doing so would provide valuable comparative insights for policymakers, investors, and researchers, supporting broader decision-making on optimal technology selection for renewable energy projects across Europe and similar climates.

Limitations and future work

While this study provides valuable insights into the performance of photovoltaic systems across Lithuania's climate zones, several limitations should be acknowledged.

Single module type and fixed tilt configuration: The analysis focused exclusively on one module model (SoliTek SOLID B.60 Bifacial 370W) and a fixed tilt system set at 30°. While this approach ensured uniformity, it excluded alternative technologies (e.g., monofacial (Matarneh, Al-Rawajfeh & Gomaa, 2022), thin-film (Ebner et al., 2015; Lee & Ebong, 2017)) or configurations (e.g., tracking systems (Amelia et al., 2020; Hafez et al., 2018)) that may perform differently under the same climatic conditions.

Use of simulated data only: This study used typical meteorological year (TMY) data from the NSRDB, which represents long-term average weather patterns but does not capture real-time variations. Consequently, short-term climatic events such as snow or temporary shading from vegetation were not included in the analysis. These omissions may lead to differences between simulated results and actual photovoltaic system performance in real conditions.
Static economic assumptions: Economic modeling was based on constant electricity sale prices, discount rates, and O&M costs. However, these variables are likely to evolve due to market dynamics, inflation, policy changes, and technological advancements.

Future research could enhance the current analysis by incorporating several additional dimensions. First, deploying experimental PV installations across the studied regions would provide real-world data to validate and refine simulation outcomes. Second, testing a wider range of photovoltaic technologies, such as monofacial or thin-film panels, would allow a broader performance comparison under uniform conditions. Third, incorporating optimization techniques for panel orientation, tilt, and tracking systems could improve energy yield estimates. Moreover, integrating storage solutions would enable modeling of self-consumption patterns and energy autonomy. Finally, simulating various economic and regulatory scenarios, such as fluctuating electricity prices or policy incentives, would offer a more robust framework for long-term investment and planning.

References

About - System Advisor Model - SAM. (n.d.). Retrieved July 1, 2025, from https://sam.nrel.gov/about-sam.html

Akstinas, V. (2017). Cohesion of statistical downscaling methods and projections of cohesion of statistical downscaling methods and projections of meteorological parameters over. Conference: CYSENI 2017 - 14th International Conference of Young Scientists on Energy Issues https://www.researchgate.net/publication/317381655

Aktas, I. S., & Ozenc, S. 2024. A Case Study of Techno-Economic and Environmental Analysis of College Rooftop for Grid-Connected PV Power Generation: Net Zero 2050 Pathway. *Case Studies in Thermal Engineering*, 56, 104272. https://doi.org/10.1016/j.csite.2024.104272

Amelia, A. R., Irwan, Y. M., Safwati, I., Leow, W. Z., Mat, M. H., & Rahim, M. S. A. (2020). Technologies of solar tracking systems: A review. IOP Conference Series: Materials Science and Engineering, 767(1). https://doi.org/10.1088/1757-899X/767/1/012052

Aqachmar, Z., Bouhal, T., & Lahrech, K. (2020). Energetic, economic, and environmental (3 E) performances of high concentrated photovoltaic large scale installations: Focus on spatial analysis of Morocco. *International Journal of Hydrogen Energy*, 45(18), 10840-10861. https://doi.org/10.1016/j.ijhydene.2020.01.210

Ayadi, O., Rinchi, B., Al-Dahidi, S., Abdalla, M. E. B., & Al-Mahmodi, M. (2024). Techno-Economic Assessment of Bifacial Photovoltaic Systems under Desert Climatic Conditions. *Sustainability*, 16(16). https://doi.org/10.3390/SU16166982

Ayompe, L. M., Duffy, A., McCormack, S. J., & Conlon, M. (2010). Validated real-time energy models for small-scale grid-connected PV-systems. *Energy*, 35(10), 4086–4091. https://doi.org/10.1016/J.ENERGY.2010.06.021

Badran, G., & Dhimish, M. (2024). Comprehensive study on the efficiency of vertical bifacial photovoltaic systems: a UK case study. *Scientific Reports*, 14(1), 1-16. https://doi.org/10.1038/S41598-024-68018-1

Bifacial, S. (n.d.). SOLID Bifacial. www.solitek.eu

Blair, N., Dobos, A. P., Freeman, J., Neises, T., Wagner, M., Ferguson, T., Gilman, P., & Janzou, S. (2014). System Advisor Model, SAM 2014.1.14: General Description. NREL Report No. TP-6A20-61019, National Renewable Energy Laboratory, Golden, CO, February, 13. https://doi.org/10.2172/1126294

Blanc, P., Espinar, B., Geuder, N., Gueymard, C., Meyer, R., Pitz-Paal, R., Reinhardt, B., Renné, D., Sengupta, M., Wald, L., & Wilbert, S. (2014). Direct normal irradiance related definitions and applications: The circumsolar issue. *Solar Energy*, 110, 561–577. https://doi.org/10.1016/J.SOLENER.2014.10.001

De Soto, W., Klein, S. A., & Beckman, W. A. (2006). Improvement and validation of a model for photovoltaic array performance. *Solar Energy*, 80(1), 78–88. https://doi.org/10.1016/J.SOLENER.2005.06.010

Ebner, R., Kubicek, B., Ujvari, G., Novalin, S., Rennhofer, M., & Halwachs, M. (2015). Optical Characterization of Different Thin Film Module Technologies. *International Journal of Photoenergy*, 2015(1), 159458. https://doi.org/10.1155/2015/159458

Erdinc, O., Paterakis, N. G., & Catalaõ, J. P. S. (2015). Overview of insular power systems under increasing penetration of renewable energy sources: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 52, 333-346. https://doi.org/10.1016/J.RSER.2015.07.104

Ferry, A., Parenti, M., Thebault, M., Ménézo, C., & Fossa, M. (2025). Optimal tilt angles for bifacial photovoltaic plants across Europe based on cumulative sky and Typical Meteorological Year data. *Solar Energy*, 293. https://doi.org/10.1016/J.SOLENER.2025.113475

GPS coordinates of Lithuania. Latitude: 55.1736 Longitude: 23.8948. (n.d.). Retrieved July 2, 2025, from https://latitude.to/map/lt/lithuania#google_vignette

Guerrero-Lemus, R., Vega, R., Kim, T., Kimm, A., & Shephard, L. E. (2016). Bifacial solar photovoltaics – A technology review. *Renewable and Sustainable Energy Reviews*, 60, 1533–1549. https://doi.org/10.1016/J.RSER.2016.03.041

Hafez, A. Z., Yousef, A. M., & Harag, N. M. (2018). Solar tracking systems: Technologies and trackers drive types – A review. *Renewable and Sustainable Energy Reviews*, 91, 754–782. https://doi.org/10.1016/J.RSER.2018.03.094

IRENA. (2021). Renewable Power Generation Costs in 2021. ISBN 978-92-9260-452-3 https://www.connaissancedesenergies.org/sites/connaissancedesenergies.org/files/pdf-pt-vue/IRENA_Power_Generation_Costs_2021_.pdf

IRENA. (2022). Renewable Generation Costs in 2022. In International Renewable Energy Agency. ISBN 978-92-9260-544-5 https://www.connaissancedesenergies.org/sites/connaissancedesenergies.org/files/pdf-pt-vue/IRENA_Renewable_power_generation_costs_in_2022.pdf

IRENA. (2024). Renewable Generation Costs in 2024. In International Renewable Energy Agency. ISBN 978-92-9260-452-3. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEC_RPGC_in_2024_2025.pdf

IRENA Renewable Power Generation Cost. (2021). Renewable Power Generation Costs in 2020. In International Renewable Energy Agency. ISBN 978-92-9260-348-9 https://solarthermalworld.org/wp-content/uploads/2021/07/irena_renewable_heat_generation_costs_2010_to_2020.pdf

Kaldellis, J. K., & Zafirakis, D. (2011). The wind energy (r)evolution: A short review of a long history. *Renewable Energy*, 36(7), 1887–1901. https://doi.org/10.1016/J.RENENE.2011.01.002

Lee, T. D., & Ebong, A. U. (2017). A review of thin film solar cell technologies and challenges. *Renewable and Sustainable Energy Reviews*, 70, 1286–1297. https://doi.org/10.1016/J.RSER.2016.12.028

Matarneh, G.A., Al-Rawajfeh, M.A., & Gomaa, M.R. (2022). Comparison review between monofacial and bifacial solar modules. *Technology Audit and Production Reserves*. https://doi.org/10.15587/2706-5448.2022.268955

Neama, N. H., &. Fakhe, R. K. A. (2024). Techno-Economic Evaluation of a Residential Photovoltaic System: A Case Study From the Residential Complex Kass Suwailem in Hilla, Iraq. *Case Studies in the Environment*, 8(1). https://doi.org/10.1525/cse.2024.2204998

NSRDB. (n.d.). Retrieved July 1, 2025, from https://nsrdb.nrel.gov/data-viewer

Paiano, A., Lagioia, G., & Ingrao, C. (2023). A combined assessment of the energy, economic and environmental performance of a photovoltaic system in the Italian context. *Science of the Total Environment*, 866, Article Number 161329. http://doi.org/10.1016/j.scitotenv.2022.161329

Renewable Energy Agency, I. (2023). Renewable Power Generation Costs in 2023. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Renewable_power_generation_costs_in_2023.pdf

Renewable Energy Agency, I. (2025). Renewable Energy Statistics 2025 Statistiques D'Énergie Renouvelable 2025 Estadísticas De Energía Renovable 2025. ISBN: 978-92-9260-675-6 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_DAT_RE_Statistics_2025.pdf

Reno, M. J., & Hansen, C. (2014). Horizontal Irradiance Clear Sky Models: Implementation and Analysis. Sandia Report, January. http://www.osti.gov/servlets/purl/1039404/

Sun, X., Khan, M. R., Deline, C., & Alam, M. A. (2018). Optimization and performance of bifacial solar modules: A global perspective. *Applied Energy*, 212, 1601–1610. https://doi.org/10.1016/J.APENERGY.2017.12.041

Tyagi, P.K., & Kumar, R. (2024). Comprehensive performance assessment of photovoltaic/thermal system using MWCNT/water nanofluid and novel finned multi-block nano-enhanced phase change material-based thermal collector: Energy, exergy, economic, and environmental (4E) perspectives. *Energy*, 312, Article Number 133575 http://doi.org/10.1016/j.energy.2024.133575

What is the optimal solar panel tilt angle? Poland and the world - Electrum. (n.d.). Retrieved August 19, 2025, from https://electrum.pl/en/what-is-the-optimal-solar-panel-tilt-angle/

Zhang, Y., Yuxin, C., Tianyi, Ch., & Lucchi, E. 2025. Optimized Community-Level Distributed Photovoltaic Generation (DPVG): Aesthetic, Technical, Economic, and Environmental Assessment of Building Integrated Photovoltaic (BIPV) Systems. *Journal of Building Engineering*, 103, 112085. https://doi.org/10.1016/j.jobe.2025.112085

Zhou, Y., Wang, J.J., Qin, Y.B., & Liu, B.X. (2024). Performance Assessment and Improvement of Photovoltaic-Thermal System based on Energy, Exergy, Economic and Environment Analysis. *Journal of Thermal Science*, 33(6), 2166-2178. http://doi.org/10.1007/s11630-024-2014-0

Funding: The research leading to these results has received funding from the project titled "Cluster for innovative energy" in the frame of the program "HORIZON-MSCA-2022-SE-01" under the Grant agreement number 101129820

Acknowledgements: This work was supported by the Centre National pour la Recherche Scientifique et Technique (CNRST), Morocco, under the PhD-ASsociate Scholarship – PASS program.

Author Contributions: Conceptualization: *Chaymae Taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene;* methodology: *Chaymae Taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene*; data analysis: *Chaymae Taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene,* writing—original draft preparation: *Chaymae Taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene*, writing; review and editing: *Chaymae taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene*; visualization: *Chaymae Taib, Zineb Aqachmar, Najiba El Amrani El Idrissi, Manuela Tvaronaviciene*. All authors have read and agreed to the published version of the manuscript.

Chaymae TAIB Ph.D. student and software engineer specialized in embedded systems with professional experience in the automotive industry. She graduated from ENSA Fès, Morocco, with a degree in embedded systems and industrial computing. Her research interests include applying artificial intelligence in healthcare and exploring innovative digital technologies.
ORCID ID: https://orcid.org/0009-0003-3060-8367

Zineb AQACHMAR engineer and associate professor-researcher at the faculty of sciences Semlalia, Cadi Ayyad university (Marrakech, Morocco). She holds an engineering degree from ENSEEIHT, Toulouse (France) and completed her Ph.D. at USMBA (Morocco) in the field of solar energy. Her research focuses on photovoltaic technologies, particularly the energy, economic, and environmental assessment of solar systems (CSP, CPV) and their applications in Morocco and Africa.
ORCID ID: https://orcid.org/0000-0003-4412-5596

Najiba EL AMRANI EL IDRISSI is a full professor of electrical engineering at the faculty of sciences and techniques, Sidi Mohamed Ben Abdellah university, Fez, Morocco. She holds a Ph.D. in electrical engineering and is a senior member of the signals, telecommunications, and smart electrical networks research team within the signals, systems, and components laboratory. She has coordinated and participated in several EU-funded research projects under FP6, FP7, Horizon 2020, and Erasmus+.
ORCID ID: https://orcid.org/0000-0001-5603-1306

Manuela TVARONAVICIENE is a professor at Vilnius Gediminas Technical university (Lithuania). Her research interests cover sustainable development, innovation, foreign direct investment, entrepreneurship, energy security and regional economic growth.
ORCID ID: https://orcid.org/0000-0002-9667-3730

This is peer-reviewed scientific journal https://jssidoi.org/ird/page/peer-review-policy

Copyright © 2025 by author(s). Publishing rights by UAB Sustainability for Regions
This work is licensed under the Creative Commons Attribution International License (CC BY).
http://creativecommons.org/licenses/by/4.0/
Open Access