



Research Commons

Publisher

Sustainability for Regions

TURNING THE SUN INTO POWER: THE NOUR MODEL FOR BOOSTING SOLAR ENERGY IN NORTHERN EUROPE***Chaymae Srati ^{1*}, Najwa Gouitaa ², Fatima Zahra Ahjyaje ³, Najiba El Amrani El Idrissi ⁴,
Jamil Toyir ⁵, Taj Dine Lamcharfi ⁶, Katarzyna Chudy-Laskowska ⁷,
Teresa Piecuch ⁸, Widera Katarzyna ⁹**^{1,2,3,4,6}Signals, Systems and Components Laboratory (LSSC), Electrical Engineering Department, University Sidi Mohamed Ben Abdellah USMBA, FST. Fez, Imouzzar Road B.P. 2202, Fez, Morocco^{1,5}Processes, Materials and Environment Laboratory (LPME), Sidi Mohamed Ben Abdellah University Polydisciplinary Faculty of Taza, FP-Taza, B.P 1223, Morocco^{7,8}Rzeszow University of Technology, University of Rzeszów. al. Tadeusza Rejtana 16C 35-959 Rzeszów, Poland⁹Opole University of Technology, Prószkowska 76 45-758 Opole, Poland⁹Centre of Sociological Research, ul. Bolesława Śmiałego 22, Szczecin Poland

E-mails: ^{1*}chaymae.srati@usmba.ac.ma (Corresponding author); ²najwa.gouitaa@gmail.com;
³fatimazahra.ahjyaje1@usmba.ac.ma; ⁴najiba.elamrani@usmba.ac.ma; ⁵jamil.toyir@usmba.ac.ma;
⁶lamcharfi_taj@yahoo.fr; ⁷kacha877@prz.edu.pl; ⁸tpiechuch@prz.edu.pl; ⁹k.widera@po.edu.pl

Received 11 August 2025; accepted 20 January 2026; published 30 March 2026

Abstract. This paper explores innovative pathways for solar energy conversion in Northern Europe, using the Noor Solar Power Station in Morocco as a benchmark. As one of the world's largest concentrated solar power plants, Noor offers key insights into high-efficiency energy production and scalable infrastructure. The study examines the feasibility of adapting similar models to the Lithuanian context, characterised by lower solar irradiance and colder climatic conditions. Through a comparative analysis, we investigate how photovoltaic systems can be optimised in Lithuania using adaptive architectural design, seasonal storage, and smart energy management. Particular attention is given to regional solar exposure, with southern and southeastern Lithuania identified as the most favourable areas for pilot implementation. By bridging the gap between high-irradiance and low-irradiance regions, this research outlines a strategic vision for sustainable solar deployment, contributing to Lithuania's long-term energy resilience and environmental goals.

Keywords: Lithuania; Solar Cells; Conversion Efficiency; Perovskite; Sustainable Energy

Reference to this paper should be made as follows: Srati, Ch., Gouitaa, N., Ahjyaje, F. Z., El Amrani El Idrissi, N., Toyir, J., Lamcharfi, T.D., Chudy-Laskowska, K., Piecuch, T., Katarzyna, W. 2026. Turning the sun into power: the NOUR model for boosting solar energy in Northern Europe. *Insights into Regional Development*, 8(1), 43-54. <http://doi.org/10.70132/m8233728827>

JEL Classifications: Q01, Q43, Q55

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

Funded by the
European Union

1. Introduction

Developing an effective and coherent energy policy, whatever the initial equation (resources, location, means), requires considerable foresight and a willingness to make long-term choices. Over the last ten years or so, the concept of energy transition has become increasingly commonplace in political discourse, particularly in Europe (Collard 2016). Today's challenge is no longer limited to identifying new solutions to meet future energy needs amid gradually depleting oil and gas reserves. It also involves developing alternative technologies capable of reducing CO₂ emissions, or even eliminating them, drawing inspiration from natural mechanisms such as photosynthesis, which uses the carbon dioxide present in the atmosphere. Science has reached a significant level of maturity, but the challenge remains considerable for both researchers and political decision-makers. Every country needs to develop a roadmap for its energy transition due to the availability of different energy resources (Kalair et al. 2021). So, the innovation plays a vital role in this transition. We can talk about energy conversion technologies such as solar thermal, photovoltaic, wind or biomass constantly evolve to become more efficient, more economical and more environmentally friendly (Redouani et al., 2024; Zemlickienė et al., 2024; Zemlickienė et al., 2024; Talbi et al., 2025; Vestertė et al., 2025; Smaliukienė & Katina, 2025; Sebbaghi et al., 2025; Amraoui et al., 2025; Chiki et al., 2025; Taib et al., 2025).

Following the closure of the Ignalina Nuclear Power Plant (INPP), Lithuania's dependence on imported fossil fuels (natural gas, oil and coal) increased considerably. In 2010-2011, the country's energy dependency reached around 82%, well above the European Union average of 53% (Gaigalis and Skema 2014). Faced with this situation, Lithuania has embarked on an energy transition policy. In 2011, renewable and indigenous energy sources accounted for 18.3% of gross domestic energy consumption. Biomass dominated this renewable mix, accounting for almost 69%, mainly in the form of firewood and agricultural residues. The country has also invested in wind power, biogas and biofuels. The idea for this research emerged from the observation of Lithuania's substantial seasonal variability in solar irradiation, which limits photovoltaic performance during winter months. Building on this contrast, it became relevant to regard the Noor solar complex not only as a technological success adapted to desert conditions, but also as a transferable model (Ab, 2020) whose principles—material optimisation, thermal management, and large-scale integration—could be reinterpreted to address the specific challenges of Baltic climates. This study examines the influence of seasonal variations in solar radiation in Lithuania and explores innovative strategies to enhance solar energy production. By leveraging the highlight absorption properties of perovskite materials, we highlight notable gains in conversion efficiency. Drawing inspiration from the Nour solar power station in Morocco, we propose integrating energy storage systems to preserve surplus energy during peak summer periods, thus addressing Lithuania's winter limitations.

2. Materials and Methods

This article was prepared based on an in-depth review of recent scientific literature and in close collaboration with specialists in energy and functional materials. The data used primarily come from scientific articles indexed in international databases such as ScienceDirect, Scopus, and Web of Science, covering the period from 2015 to 2024. Quite a few scientific publications were consulted and analysed, focusing mainly on the properties, performance, and high efficiency of materials used in energy conversion. The analysis was carried out using recognised methodologies for evaluating experimental data and device performance. Comparisons between studies were made using standardised indicators that considered energy efficiency, material stability, and environmental impact.

3. Status of Renewable Energy Usage in Lithuania

The structure of Lithuania's renewable energy consumption highlights a clear predominance of traditional biomass sources (Gaigalis & Katinas, 2020; Official Statistics Portal (n.d.)). This distribution underscores Lithuania's continued reliance on biomass-based resources. It highlights the need to diversify towards high-efficiency, low-carbon technologies, particularly in light of seasonal solar variability and energy security goals.

Renewable energy resources consumption structure, 2022

Per cent

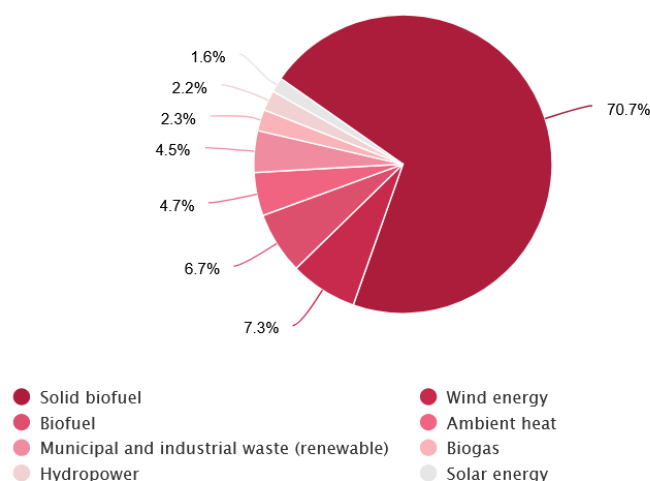


Figure 1. Composition and distribution of the renewable energy in gross inland fuel and energy consumption in Lithuania in 2022

Source: Official Statistics Portal (n.d.) Energy https://osp.stat.gov.lt/en_GB/energetika

In 2017, energy consumption in Lithuania was distributed across several key sectors. The transport sector accounted for the largest share, consuming 37% of the total energy, followed by households at 27%, highlighting the importance of residential energy use. Industry accounted for 20% of total energy consumption, while commercial and public services accounted for 13%. The remaining 3% was attributed to other sectors. This distribution underscores the dominance of transport and households in Lithuania's energy consumption profile during that year. Since the definitive closure of the Ignalina nuclear power plant in 2009, Lithuania has progressively increased its dependence on electricity imports, reaching around 63% of its national consumption in 2023, mainly via interconnections with Poland, Latvia and Sweden. This situation has worsened against a backdrop of soaring energy prices, with the cost of electricity doubling and the cost of gas for households increasing fivefold between 2020 and 2023 (Report 2025; sample-energy-data n.d.). In response to this energy vulnerability, the Lithuanian authorities have launched an ambitious strategy to cover 70% of electricity production from local sources by 2030. This transition is primarily driven by the development of renewable energy, of which bioenergy currently accounts for the largest share, thanks to the use of wood and agricultural waste. In 2023, wind energy accounted for almost 42% of renewable electricity production, compared with 17% for hydroelectricity, while solar energy is making slow progress (Lithuania - Countries & Regions - IEA n.d.). However, the country continues to experience substantial seasonal variability, particularly in winter, when sunshine levels fall, and demand rises. This constraint underscores the need to strengthen energy storage capacities and adapt conversion technologies to local climatic conditions to ensure stable, sustainable energy production. Lithuania faces major climatic challenges, with low winter solar irradiation limiting photovoltaic production. Its heavy dependence on energy imports makes it vulnerable to fluctuations in the European market. At the same time, the need to reduce emissions calls for a rapid transition to local renewable sources. These

constraints call for innovative solutions that combine storage, energy efficiency, and climate-adapted technologies.

4. The Noor Solar Station (Morocco): A Benchmark of Solar Innovation

Morocco attaches particular importance to clean energies as a means of reconciling socio-economic development and environmental protection. Committed to combating climate change, the country adopted a "new national energy strategy" in March 2009. The strategy aims to strengthen the security of supply, ensure greater energy availability, improve the competitiveness of the productive sector, and protect the environment. The strategy also marks the start of a genuine energy transition, placing renewable energies and energy efficiency (EE) at the heart of national priorities. Among Morocco's renewable energy resources, solar energy holds the highest potential and significance (El Mghouchi, Ajzoul, and El Bouardi 2016). This is reflected in the implementation of large-scale renewable energy projects, such as the NOOR I solar project in Ouarzazate. This investigation is critical for several reasons. The region boasts vast stretches of flat desert, perfect for installing large-scale solar power plants, and its low population density limits land-use conflicts. Ouarzazate enjoys one of the highest levels of sunshine in the world, with a DNI (Direct Normal Irradiation) of around 2,420 kWh/m²/year (Figure 2). This level of sun is ideal for CSP technologies, which require high levels of direct irradiation to be effective. This level of sunshine is perfect for CSP technologies, which require high levels of direct irradiation to be effective (Ennaceri et al. 2018).

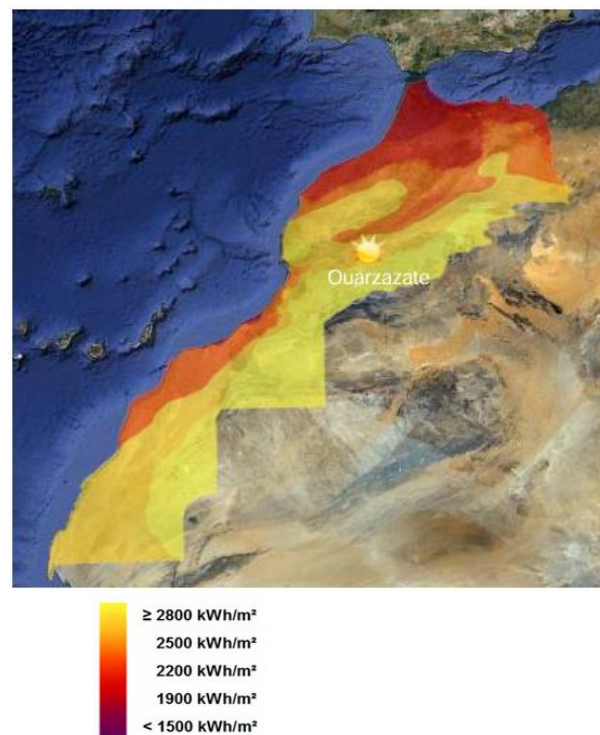


Figure 2. Map of direct solar irradiation in Morocco, showing the city of Ouarzazate (Masen, 2012).

In this section, we present the DNI and GHI values generated by several satellite databases. For comparison, the annual average GHI and DNI using different satellite-based databases (NASASSE, PVGIS-Helioclim, Climate-SAFPVGIS and Solar Med Atlas) are presented in Figure 3. The solar resource assessment for the Ouarzazate region, illustrated in Figure 4 of the study, was conducted by Bousselamti and Cherkaoui (2019), highlighting the site's exceptional potential for photovoltaic (PV) and concentrated solar power (CSP) applications. Figure 4(a) displays the monthly average variation of global horizontal irradiation (GHI) and direct normal irradiation (DNI).

The GHI reaches its peak values between April and August, with daily averages approaching 8500 Wh/m²/day. In parallel, the DNI is particularly elevated from January to June, exceeding 8000 Wh/m²/day. These high levels of both global and direct irradiance underscore the year-round solar abundance in the region, making it highly suitable for solar energy systems. Notably, the annual DNI surpasses the economic threshold for CSP deployment, generally set between 1900 and 2000 kWh/m²/year. Figure 1(b) provides the annual average hourly profiles of GHI, DNI, and ambient temperature. Both irradiance types exhibit typical diurnal behaviour, peaking between 12:00 and 14:00, which aligns well with periods of high electricity demand. Notably, the average daytime ambient temperature remains below 25°C, a favourable condition for PV systems whose efficiency typically declines at elevated temperatures. Moreover, the DNI remains consistently high between 08:00 and 18:00, ensuring efficient operation of CSP collectors throughout the solar window.

These results confirm that Ouarzazate offers optimal climatic conditions for the deployment of hybrid PV-CSP systems. The combination of strong direct and diffuse irradiance, along with moderate ambient temperatures, not only enhances overall system performance but also supports stable, predictable energy generation. This is particularly advantageous for hybrid systems equipped with thermal energy storage (TES), enabling flexible dispatch and continuous power supply even beyond daylight hours.

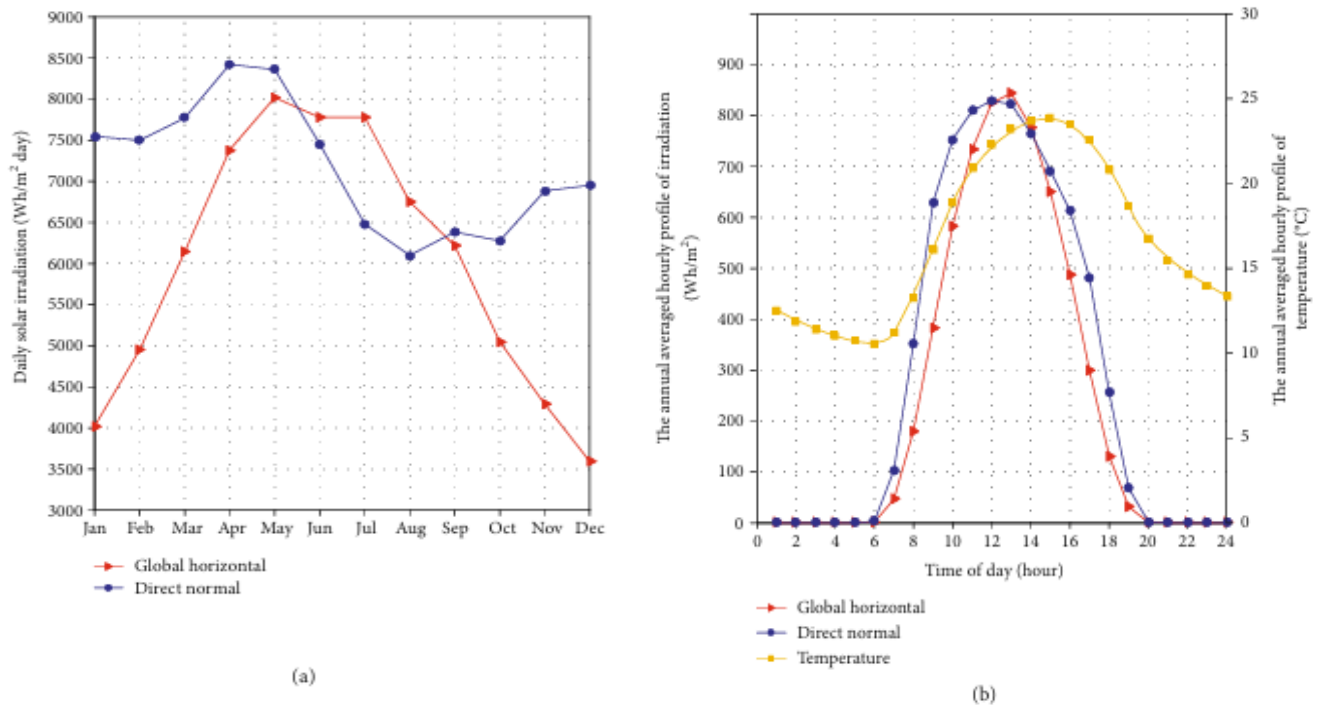


Figure 3 (a) Monthly average values of global and direct irradiation for Ouarzazate

Figure 4 (b) The annual averaged hourly global horizontal irradiation, direct normal irradiation, and temperature profile for Ouarzazate (Bousselamti & Cherkaoui 2019).

The Noor solar complex in Ouarzazate, Morocco, is one of the world's most significant solar projects, combining several complementary solar technologies. The majority of its installations use Concentrated Solar Power (CSP) technology, which, unlike conventional photovoltaic systems, concentrates sunlight to heat a thermal fluid, enabling electricity to be generated by a turbine (Table 1).

Table 1. Surface, Capacity, and Storage Features of Noor Complex

Phase	Technology	Surface area	Electrical power	Type of Cells or System	Thermal Storage
Noor-I	Parabolic Trough CSP	~450 hectares (~4.5 km ²)	~160 MW	No PV heat transfer fluid system	3 hours
Noor-II	Parabolic Trough CSP	~680 hectares (~6.8 km ²)	~200 MW	Same as above	7 hours
Noor-III	Central Tower CSP	~750 hectares (~7.5 km ²)	150 MW	Same as above	7-8 hours
Noor-IV	Photovoltaic (PV)	~210 hectares (~2.1 km ²)	~72 MW	Crystalline silicon solar cells	None

The first phase of the project, Noor I, uses parabolic trough mirrors to concentrate the sun's rays on tubes containing a heat transfer fluid, with an installed capacity of 160 MW and a thermal storage system with a duration of around 3 hours. The next phase, Noor II, uses the same technology, with a capacity of 200 MW, while improving storage performance to 7 hours. At the same time, Noor III adopts a different configuration, based on a central tower. Heliostats (adjustable mirrors) concentrate the sun's rays onto a receiver placed at the top of a tower, enabling higher temperatures (~565°C) to be reached, and thus greater thermal efficiency. The system incorporates a molten-salt storage system to ensure production for up to 7 or 8 hours after sunset. Complementing these thermal technologies, the fourth phase of the project, Noor IV, is based on a conventional photovoltaic approach, with a capacity of 72 MW. This plant is likely to use mono- or polycrystalline crystalline silicon cells. Unlike previous phases, this technology produces electricity directly, without thermal fluid or integrated storage. Trackerless photovoltaics are particularly attractive for their reduced production and operating costs and require less maintenance. These systems operate without any additional energy input, unlike panels equipped with motorised trackers, which consume a small amount of energy to orient themselves according to the sun. However, dual-axis trackers can deliver around 30% greater efficiency than fixed systems, which may justify their use under optimal sunlight conditions.

5. Towards Resilient Photovoltaics: Adapting Solar Technologies to Lithuanian Climatic Conditions

In the context of optimising solar energy deployment across Lithuania, identifying regions with high solar irradiation is essential for ensuring both technical and economic viability (Figure 5). Based on long-term photovoltaic output data, several areas stand out as particularly favourable for the establishment of solar power plants. The southwestern and southern regions of the country offer the highest solar potential, with Tauragė, Marijampolė, and Alytus receiving more than 1070 kWh/kWp annually. These locations provide stable, efficient conditions for large-scale photovoltaic installations. The southern part of Kaunas also emerges as a promising site due to its advantageous solar yield and central location. Additionally, the coastal region of Klaipėda—despite its relatively humid climate—has strong potential for hybrid energy systems combining solar and wind power. The southern outskirts of Vilnius are equally notable, offering both sufficient solar exposure and accessibility, making them ideal for urban and peri-urban solar energy projects. Based on the comparative results shown in Figure 6, this analysis can be further extended beyond Lithuania to include Poland and Italy. The results indicate that Lithuania and Poland exhibit very similar conditions in terms of both theoretical and practical photovoltaic potential, reflecting comparable climatic and solar environments. In contrast, Italy shows characteristics more closely aligned with Morocco, suggesting that these two countries share similar solar resource profiles and PV potential patterns.

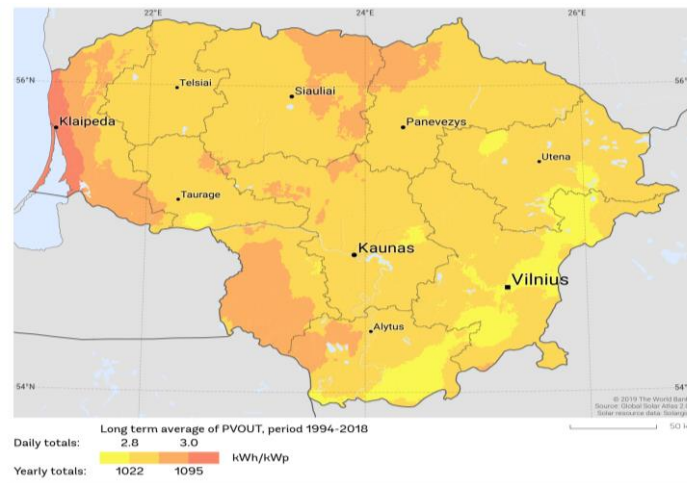
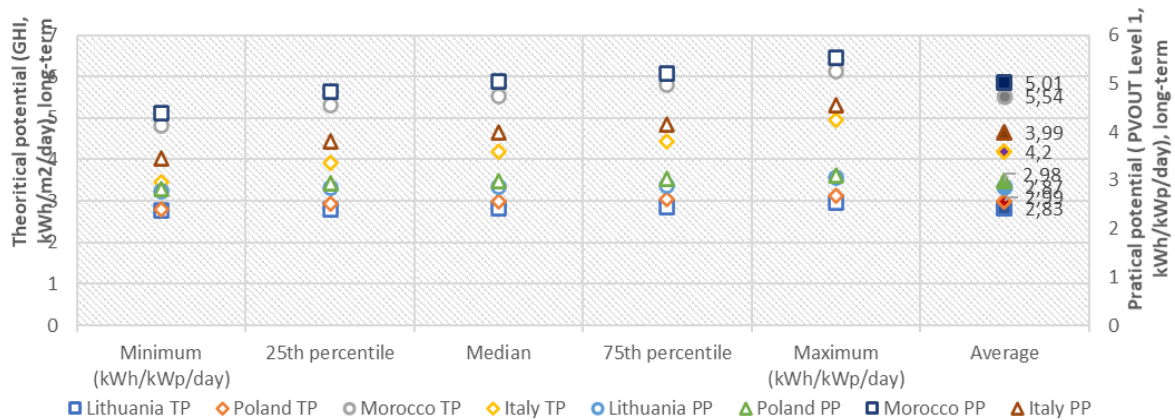


Figure 5. Map of Lithuania solar Direct irradiation



Source: World Bank (2020)

Figure 6. Comparison of descriptive characteristics of theoretical and practical PV potential for Lithuania, Morocco, Poland and Italy

Table 2. Matching Solar Technologies to Regional Solar Profiles in Lithuania

Technology / Material	Efficiency (approx.)	Advantages	Recommended Zones in Lithuania
Hybrid Halide Perovskites (HaPs)	20–25% (lab scale)	Excellent light absorption, performs well in low light, low cost	Kaunas, Alytus, Vilnius
Tandem Cells (Silicon + Perovskite)	Up to 30% (lab scale)	Broad spectrum absorption, high efficiency, suited to variable climates	Kaunas, Marijampolė, Vilnius
Cadmium Telluride (CdTe)	18–22%	Performs well in cold and diffuse light conditions	Klaipėda, Šiauliai
Copper Indium Gallium Selenide (CIGS)	17–20%	Strong absorption, flexible, tolerant to partial shading	Tauragė, Marijampolė, rooftops or uneven surfaces
Silicon Heterojunction (HJT)	22–24%	High performance in low irradiance, stable in cold temperatures	Alytus, Tauragė, residential zones near Vilnius

To fully harness the solar potential in regions such as Tauragė, Marijampolė, Alytus, southern Kaunas, and the Klaipėda coast, it is crucial to deploy photovoltaic technologies capable of capturing a broad range of the solar spectrum, especially under variable weather conditions (Table 2). Among the most promising materials, hybrid halide perovskites stand out for their high efficiency and excellent light absorption properties, even in diffuse sunlight. Their combination with silicon in tandem solar cells allows for expanded spectral coverage and enhanced efficiency, power densities approaching 500 W/m² in the best conditions (Höranter & Snaith 2017; Li et al. 2021; Tang et al. 2024), making them ideal for Lithuania's temperate climate. Additionally, cadmium telluride (CdTe) has a typical power density of around 120-150 W/m², depending on sunlight conditions (Ferekides and Britt 1994; Gupta, Parikh, and Compaan 2006; Luque and Hegedus 2011). CIGS (copper indium gallium selenide), for example, a 140 W flexible CIGS module weighs around 2.1 kg and measures 2583 mm × 348 mm, corresponding to a power density of around 140 W/m², flexible with good low-light performance (Repins et al. 2009; Song et al. 2010). Those technologies offer robust performance under partial shading and cooler temperatures, which are common in the coastal and northern parts of the country. Finally, silicon-based heterojunction (HJT) cells deliver excellent performance in low-light conditions and maintain high efficiency across seasonal variations. Heterojunction silicon (HJT) solar cells produce a high electrical energy density of around 268 W/m² under standard conditions, thanks to a record efficiency of almost 27% and excellent management of electrical losses (Lin et al. 2023; Wang et al. 2024). Integrating these advanced materials into solar infrastructure would significantly improve energy yields and ensure the long-term viability of solar stations in Lithuania's most irradiated regions.

6. Enhancing Solar Energy Reliability Through Advanced Energy Storage Integration

The integration of energy storage systems with high-performance photovoltaic (PV) technologies is a crucial step toward achieving a stable, resilient, and efficient renewable energy infrastructure. (Kalair et al. 2021) While next-generation PV materials such as hybrid halide perovskites, tandem solar cells, and CIGS modules offer remarkable conversion efficiencies and adaptability to varying climatic conditions, their intermittent nature—dependent on sunlight availability—presents a key challenge for continuous energy supply.

To address this, advanced battery storage systems such as lithium-ion offer high power density, typically between 200 and 700 W/kg (Patel, 2023), enabling rapid discharges and high instantaneous power and high charge/discharge efficiency (~90%). Li-ion batteries generally have an average lifespan of around 500 cycles, depending on chemistry and use (Singh et al. 2014). The density for Sodium-Ion Batteries is 50–100 Wh/kg (Slater et al. 2013), and for vanadium redox flow batteries, it is 100 Wh/kg (Maksudovna Vafaeva and Sanjeeva 2024). These systems are designed to store large quantities of electricity generated during peak solar hours and release it during periods of low solar radiation, including nights and overcast days. In particular, flow batteries and emerging solid-state technologies offer long cycle life, high safety, and deep discharge capabilities, making them suitable for long-term and large-scale storage applications.

When strategically deployed alongside high-performance PV systems—especially in high-yield zones like Alytus, Tauragė, and Klaipėda—these storage solutions can significantly reduce energy curtailment, stabilise local grids, and facilitate the integration of solar power into urban and rural energy networks. Furthermore, the coupling of PV with storage not only improves the economic value of solar installations by enabling time-shifting of electricity use but also supports energy independence and decarbonisation goals on a national scale. This radar chart (Figure 7) compares two solar energy conversion strategies—high-efficiency photovoltaic systems combined with energy storage and concentrated solar power (CSP)—across five key criteria: climate suitability, diffuse-light performance, storage potential, installation cost, and technical complexity.

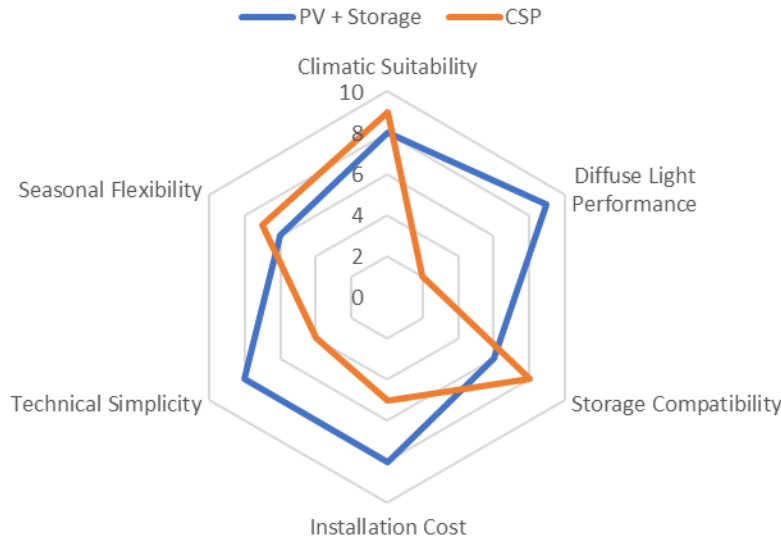


Figure 7. Comparative analysis of PV + storage versus CSP technologies in Baltic climates

The results highlight that PV + storage systems are better suited to the Lithuanian context, offering better performance under low solar irradiance and greater flexibility. In contrast, CSP systems, while efficient in high-sunlight environments and capable of thermal storage (as in Ouarzazate), are less effective under the variable, diffuse light conditions typical of northern climates.

Conclusions

By integrating the Noor Station's large-scale vision with the realities of the Lithuanian climate and geography, this project offers a compelling model for energy transition in northern Europe. With a moderate solar irradiance of $\sim 1,000 \text{ kWh/m}^2/\text{year}$ and an optimised surface area of 100 hectares in Klaipėda, Lithuania, the potential for clean, stable energy production is up to 104 GWh annually. The use of CIGS thin-film photovoltaic technology ensures both performance under diffuse light and adaptability to local weather variations.

From an economic perspective, the transposition of a Noor-inspired solar project to Lithuania reveals significant profitability potential. While annual solar irradiation in Klaipėda is significantly lower than in desert regions, several operational advantages offset this limitation. Unlike Morocco, where dust and sandstorms necessitate frequent, costly cleaning operations, Lithuania benefits from a humid, rainy climate that naturally maintains the cleanliness of photovoltaic modules, thereby reducing operating costs. In addition, lower average temperatures improve conversion efficiency by mitigating thermal losses, and the reduced intensity of ultraviolet radiation may prolong module lifetime. These climatic characteristics suggest that, despite lower irradiation levels, the Lithuanian context offers a favourable framework for cost-effective large-scale solar deployment, provided that seasonal variability is addressed through adequate storage and grid-integration strategies.

This analysis demonstrates that, even in non-desert climates, solar infrastructure can be not only viable—but strategically powerful. Lithuania is no longer merely a consumer of renewable innovation; it now stands as a potential architect of its own solar future.

References

- Ab, Litgrid. 2020. Scenario Building for the Evolution of Lithuanian Power Sector for 2020 – 2050. https://lsta.lt/wp-content/uploads/2020/12/201217-Scenario-building-for-Lithuanian-electric-power-sector_final-report.pdf
- Amraoui, B., Zemlickienė, V., & El Amrani El Idrissi, N. 2025. Renewable energy clusters: the cases of leading countries, lessons applicable to Morocco. *Insights into Regional Development*, 7(1), 93-108. <https://doi.org/10.70132/w8428438283>
- Bousselamti, Loubna, and Mohamed Cherkaoui. 2019. Modelling and Assessing the Performance of Hybrid PV-CSP Plants in Morocco: A Parametric Study. *International Journal of Photoenergy*. <https://doi.org/10.1155/2019/5783927>
- Chiki, Z., El Boutalbi, Y., Jafrane, C., Katina, J., El Amrani El Idrissi, N., Lamcharfi, T., & Idrissi Kandri, N. 2025. Renewable energy landscapes: a comparative analysis of Lithuania's, Europe's, and Africa's green strategies. *Insights into Regional Development*, 7(1), 10-23. <https://doi.org/10.70132/c7824282627>
- Collard, F. 2016. La transition énergétique <https://shs.cairn.info/revue-courrier-hebdomadaire-du-crisp-2016-36-page-5?lang=fr>
- El Mghouchi, Y., T. Ajzoul, & El Bouardi, A. 2016. Prediction of Daily Solar Radiation Intensity by Day of the Year in Twenty-Four Cities of Morocco. *Renewable and Sustainable Energy Reviews*, 53, 823-831. <https://doi.org/10.1016/j.rser.2015.09.059>
- Ennaceri, Houda et al. 2018. Direct Normal Irradiation-Based Approach for Determining Potential Regions for Concentrated Solar Power Installations in Morocco. *International Journal of Ambient Energy*, 39(1), 78-86. <http://doi.org/01430750>
- Ferekides, C., & Britt, J. 1994. CdTe Solar Cells with Efficiencies over 15%. *Solar Energy Materials and Solar Cells*, 35(C), 255-262. [https://doi.org/10.1016/0927-0248\(94\)90148-1](https://doi.org/10.1016/0927-0248(94)90148-1)
- Fund, Clean Technology. 2012. Ouarzazate Solar Complex Phase 1: Up to 160MW CSP Trough. https://www.esmap.org/sites/default/files/esmap-files/Masen_WREF_2012.pdf
- Gaigalis, V., & Katinas, V. 2020. Analysis of the Renewable Energy Implementation and Prediction Prospects in Compliance with the EU Policy: A Case of Lithuania. *Renewable Energy*, 151, 1016-1027. <https://doi.org/10.1016/j.renene.2019.11.091>
- Gaigalis, V., & Skema, R. 2014. Sustainable Economy Development and Transition of Fuel and Energy in Lithuania after Integration into the European Union. *Renewable and Sustainable Energy Reviews*, 29, 719-733. <https://doi.org/10.1016/j.rser.2013.08.100>
- Gupta, A., Parikh, V., & Compaan, A.D. 2006. High Efficiency Ultra-Thin Sputtered CdTe Solar Cells. *Solar Energy Materials and Solar Cells*, 90(15), 2263-2271. <https://doi.org/10.1016/j.solmat.2006.02.029>
- Hörantner, M. T., & Snaith, H. J. 2017. Predicting and Optimising the Energy Yield of Perovskite-on-Silicon Tandem Solar Cells under Real World Conditions. *Energy and Environmental Science*, 10(9), 1983-1993. <https://doi.org/10.1039/C7EE01232B>
- Kalair, A. et al. 2021. Role of Energy Storage Systems in Energy Transition from Fossil Fuels to Renewables. *Energy Storage*, 3(1), 1-27. <https://doi.org/10.1002/est2.135>
- Li, T. T. et al. 2021. Two-Terminal Perovskite-Based Tandem Solar Cells for Energy Conversion and Storage. *Nano-Micro Small*, 17(23), 1-24. <https://doi.org/10.1002/smll.202006145>
- Lin, H. et al. 2023. Silicon Heterojunction Solar Cells with up to 26.81% Efficiency Achieved by Electrically Optimised Nanocrystalline-Silicon Hole Contact Layers. *Nature Energy*, 8(8), 789-799. <https://doi.org/10.1038/S41560-023-01255-2>
- Lithuania - Countries & Regions - IEA. Sources of electricity generation (April 15, 2025). <https://www.iea.org/countries/lithuania/electricity>
- Luque, A., & Hegedus, S. 2011. Handbook of Photovoltaic Science and Engineering. Handbook of Photovoltaic Science and Engineering. <https://doi.org/10.1002/9780470974704>
- Maksudovna Vafaeva, K., & Sanjeeva, P. 2024. Comparative Analysis of Lithium-Ion and Flow Batteries for Advanced Energy Storage Technologies. MATEC Web of Conferences, 392, 01176. <https://doi.org/10.1051/mateconf/202439201176>
- Official Statistics Portal (n.d.) Energy https://osp.stat.gov.lt/en_GB/energetika

Patel, T. 2023. A Comparative Study of Lithium-Ion and Sodium-Ion Batteries: Characteristics, Performance, and Challenges. A Comparative Study of Lithium-ion and Sodium-ion Batteries: Characteristics, Performance, and Challenges. <https://open.fau.de/server/api/core/bitstreams/63e245bb-876b-4b7d-96f6-c5f6b266f2de/content>

Redouani, A., Ikmel, G., Zared, K., Čyras, G., & El Amrani El Idrissi, N. 2024. A comprehensive review of integrated energy storage batteries in renewable energy stations: technological advancements, challenges and future trends. *Insights into Regional Development*, 6(3), 40-52. <https://doi.org/10.70132/s6562942267>

Smaliukienė, R., & Katina, J. 2025. Exploring renewable energy future through household energy behavior: cases of Lithuania and Morocco. *Insights into Regional Development*, 7(2), 109-122. <https://doi.org/10.70132/z7463939983>

Sebbaghi, S., Aqachmar, Z., El Amrani El Idrissi, N., & Tvaronavičienė, M. 2025. Optimisation of building air conditioning using a hybrid cogeneration system with photovoltaic energy. *Insights into Regional Development*, 7(3), 83-93. <https://doi.org/10.70132/n7563347882>

World Bank. 2020. Solar photovoltaic power potential by country Factsheet Page. 2020. <https://documents1.worldbank.org/curated/en/466331592817725242/pdf/Global-Photovoltaic-Power-Potential-by-Country.pdf>

Repins, I. et al. 2009. Required Material Properties for High-Efficiency CIGS Modules. Proceedings Volume 7409, Thin Film Solar Technology; 74090M <https://doi.org/10.1117/12.828365>

Singh, L. et al. 2014. Comparative Dielectric Studies of Nanostructured BaTiO₃, CaCu₃Ti₄O₁₂ and 0.5BaTiO₃· 0.5CaCu₃Ti₄O₁₂ Nano-Composites Synthesised by Modified Sol-Gel and SolidState Methods. *Materials Characterisation*, 96, 54-62. <https://doi.org/10.1016/j.matchar.2014.07.019>

Slater, M. D., Donghan, K., Lee, F., & Johnson, Ch. S. 2013. Sodium-Ion Batteries. *Advanced Functional Materials*, 23(8), 947-958. <https://doi.org/10.1002/adfm.201200691/pdf/10.1002/adfm.201200691>

Song, S. H. et al. 2010. Structure Optimisation for a High Efficiency CIGS Solar Cell. 2010 35th IEEE Photovoltaic Specialists Conference: 2488-2492. <https://doi.org/10.1109/PVSC.2010.5614724>

Taib, C., Aqachmar, Z., El Amrani El Idrissi, N., & Tvaronavičienė, M. 2025. Technical and economic evaluation of photovoltaic panels: a case study based on interdisciplinary approach. *Insights into Regional Development*, 7(3), 123-136. <https://doi.org/10.70132/p6943275885>

Talbi, L., Abarkan, M., Saber, F. E., Louardi, A., & Vestertė, J., El Amrani El Idrissi, N., & Katina, J. 2025. Analysis of solar and wind energy utilisation in Europe and Africa. *Insights into Regional Development*, 7(3), 10-22. <https://doi.org/10.70132/z8468559752>

Tang, J. et al. 2024. Power Generation Density Boost of Bifacial Tandem Solar Cells Revealed by High Throughput Optoelectrical Modelling. *Energy & Environmental Science*, 17(16), 6068-6078. <https://doi.org/10.1039/D4EE01173B>

Vestertė, J., Skačkauskienė, I., El Amrani El Idrissi, N., & Zared, K. 2025. Challenges and opportunities of digitalising Morocco's renewable energy. *Insights into Regional Development*, 7(1), 58-82. <https://doi.org/10.70132/q3292783863>

Wang, G. et al. 2024. 27.09%-Efficiency Silicon Heterojunction Back Contact Solar Cell and Going Beyond. *Nature Communications*, 15(1), 1-12. <https://doi.org/10.1038/s41467-024-53275-5>

Zemlickienė, V., Amraoui, B., & El Amrani El Idrissi, N. 2024. Analysis of Morocco's renewable energy production and transmission potential. *Insights into Regional Development*, 6(2), 64-78. [https://doi.org/10.9770/ird.2024.6.2\(4\)](https://doi.org/10.9770/ird.2024.6.2(4))

Author Contributions: Conceptualisation: *Chaymae Srati*; Methodology: *Chaymae Srati, Fatima Zahra Ahjyaje, Najiba El Amrani El Idrissi*. Writing—original draft preparation: *Chaymae Srati*, Data analysis: *Najwa Gouitaa, Fatima Zahra Ahjyaje, Najiba El Amrani El Idrissi, Jamil Toyir, Taj dine Lamcharfi*; writing; review and editing: *Najwa Gouitaa, Fatima Zahra Ahjyaje, Jamil Toyir, Najiba El Amrani El Idrissi, Taj dine Lamcharfi, Katarzyna Chudy-Laskowska*. Visualisation: *Najwa Gouitaa, Fatima Zahra Ahjyaje, Jamil Toyir, Najiba El Amrani El Idrissi, Taj dine Lamcharfi, Teresa Piecuch, Katarzyna Widera*. All authors have read and agreed to the published version of the manuscript.

Chaymae SRATI is a PhD student at the Laboratory of Signals, Systems and Components, University of Sidi Mohamed bin Abdellah, Morocco. She graduated as a Master's degree in Materials and Process engineering at faculty of Science and Technology of Fez, Sidi Mohamed Ben Abdellah University, Morocco, in 2023.

ORCID ID: <https://orcid.org/0009-0006-5460-5461>

Najwa GOUITAA defended her doctoral thesis in Materials Science at the Signals, Systems and Components Laboratory (LSSC), attached to the Faculty of Science and Technology of Fez, Sidi Mohamed Ben Abdellah University, Morocco, in 2020. She was a member of the Signals, Systems and Components Laboratory during her doctoral work.

ORCID ID: <https://orcid.org/0000-0003-0480-1481>

Fatima Zahra AHJYAJE is a full-time professor at the Laboratory of Signals, Systems and Components, University of Sidi Mohamed bin Abdellah, Morocco. She received her PhD in organic chemistry from the faculty of science of University of Sidi Mohamed bin Abdellah in Morocco in 2000.

ORCID ID: <https://orcid.org/0009-0007-3991-6621>

Najiba EL AMRANI EL IDRISSE is a full-time professor at the Laboratory of Signals, Systems and Components, University of Sidi Mohamed bin Abdellah, Morocco. She received her PhD in Electrotechnics and Power Electronics from the Mohammedia School of Engineering in Morocco in 2004. She graduated as an Engineer in the Electrical Engineering specialty of Computer Systems in 1984. Her research interests include electrical engineering, ICT, and electrical power electronics.

ORCID ID: <https://orcid.org/0000-0001-5603-1306>

Jamil TOYIR is a full-time professor at the Laboratory of Processes, Materials and Environment Laboratory (LPME), polydisciplinary faculty of taza, University of Sidi Mohamed bin Abdellah, Morocco.

ORCID ID: <https://orcid.org/0000-0002-6963-7259>

Taj Dine LAMCHARFI is a full-time professor at the Laboratory of Signals, Systems and Components, University of Sidi Mohamed bin Abdellah, Morocco.

ORCID ID: <https://orcid.org/0000-0003-4826-8893>

Katarzyna CHUDY-LASKOWSKA is assistant profesor at Rzeszow University of Technology, Faculty of Management, Department of Quantitative Methods.

ORCID ID: <https://orcid.org/0000-0002-7797-2858>

Teresa PIECUCH is a full-time professor at Rzeszow University of Technology, Faculty of Management, Department of Enterprise Management.

ORCID ID: <https://orcid.org/0000-0003-2656-662X>

Katarzyna WIDERA is assistant profesor at Opole University of Technology, Faculty of Economic and Management, Department of Economics, Finance, Regional Research and Quantitative Methods.

ORCID ID: <https://orcid.org/0000-0003-0651-8049>

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

Copyright © 2026 by author(s). Publishing rights by [UAB Sustainability for Regions](https://www.uab.edu.pl/en)

This work is licensed under the Creative Commons Attribution International License (CC BY).

<http://creativecommons.org/licenses/by/4.0/>



Open Access