Smart Solar Energy Modeling for VN-Engineering

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Introduction

As global demand for sustainable energy continues to rise, companies like VN-Engineering are actively seeking innovative pathways to expand their services. Operating in Groningen, the company envisions transitioning from traditional solar panel installation toward integrated, smart solar energy solutions. These solutions demand not just technological upgrades, but an analytical framework to assess and enhance solar system performance. In this report, we explore three foundational modeling approaches—statistical, structural causal, and physical—and outline how each can be leveraged to improve solar panel production, installation, and maintenance. Through a scientific examination of these models, we propose services that can elevate VN-Engineering's capabilities in offering tailored, high-performance solar energy systems.

1. Statistical Model

Statistical models serve as powerful tools to uncover patterns in solar panel performance across different locations, panel types, and environmental conditions. These models rely on data collected from historical energy output, weather logs, material degradation, and operational parameters to perform inferential analysis.

By applying techniques such as regression analysis, hypothesis testing, and time-series decomposition, VN-Engineering can compare the yield of various panels under comparable conditions. For instance, given a dataset of daily energy output for multiple panel models, statistical inference allows identification of consistently high-performing panels across weather variations.

A valuable application would be the generation of annual comparative yield reports, allowing customers to assess expected returns based on empirical data. Additionally, VN-Engineering can develop performance benchmarking dashboards to monitor how an individual customer's system fares against regional averages. This would not only provide transparency but also facilitate early detection of underperformance.

However, these models have limitations. They excel in identifying correlations but fall short of explaining causal relationships. For example, a panel's superior yield in a region might be attributed to sunlight hours, but the model may not differentiate whether this is due to altitude, air clarity, or orientation. Moreover, statistical accuracy depends on the granularity, completeness, and duration of the dataset, making predictions unreliable in data-sparse environments.

2. Structural Causal Model

Unlike statistical models, structural causal models (SCMs) aim to represent the directional relationships among variables, allowing not just prediction but also the simulation of interventions. By building a causal diagram that links factors like solar irradiance, panel angle, temperature, and cleaning intervals to energy output, VN-Engineering can estimate how future changes will impact performance.

Such causal modeling supports services like proactive maintenance forecasting. For example, using weather predictions and causal influence graphs, the company can advise clients on when to clean or inspect panels to prevent efficiency drops. Similarly, SCMs can help optimize new installations by simulating outcomes under alternative configurations before finalizing system layouts.

Furthermore, SCMs can enable long-term financial planning tools. Clients planning to invest in larger systems can benefit from yield projections that consider predicted urban development (potential shading), climate trends, or infrastructure changes.

Nonetheless, SCMs are contingent on the accuracy of the underlying causal assumptions. Misrepresenting dependencies—such as assuming temperature always negatively impacts output—can skew results. These models also require high-quality, domain-specific data to parameterize the causal graphs and validate their predictions. Moreover, rare or emergent phenomena (e.g., unprecedented climate events) may not be represented in the causal structure, reducing model adaptability.

3. Physical Model

Physical models ground their predictions in the fundamental principles of physics. These models calculate expected solar panel output using equations involving solar angle of incidence, geographic latitude, azimuth, altitude, shading, and panel efficiency.

For VN-Engineering, implementing physical models can transform the design and installation process. Site-specific assessments—combining geospatial mapping with solar trajectory calculations—allow optimization of panel orientation and tilt. This enhances yield by maximizing direct irradiance exposure. Additionally, physical modeling can identify thermal losses or mismatches due to wiring and inverter limitations.

A particularly compelling service would be 3D simulation and modeling of rooftops and solar farms. Using drone imagery and LIDAR data, VN-Engineering can virtually simulate energy output under varying seasonal conditions. Such tools are valuable not only for system layout but also for obtaining construction permits and convincing stakeholders.

However, physical models often rely on assumptions of ideal conditions—uniform irradiance, clear skies, and static environments. In practice, transient shading, dust accumulation, and component wear introduce discrepancies between theoretical and actual yields. To mitigate this, physical models should be coupled with real-time sensor feedback to recalibrate assumptions and update predictions. Integrating hybrid models that combine physical laws with statistical corrections can also enhance prediction fidelity.

Conclusion

The integration of statistical, causal, and physical models offers VN-Engineering a multifaceted toolkit to design, monitor, and optimize solar energy systems. Each model contributes unique strengths: statistical models provide data-driven insights for comparative analysis; causal models offer foresight and decision-making under uncertainty; and physical models enable rigorous, site-specific system optimization. By combining these modeling approaches with intelligent services—such as predictive maintenance, dynamic layout design, and data-informed consulting—VN-Engineering can differentiate itself in a rapidly evolving renewable energy landscape. Through this synergy of science and service, the company can not only enhance operational performance but also help accelerate the transition to a more sustainable future.