White Paper

The Value of Measurements

for Solar Energy Projects

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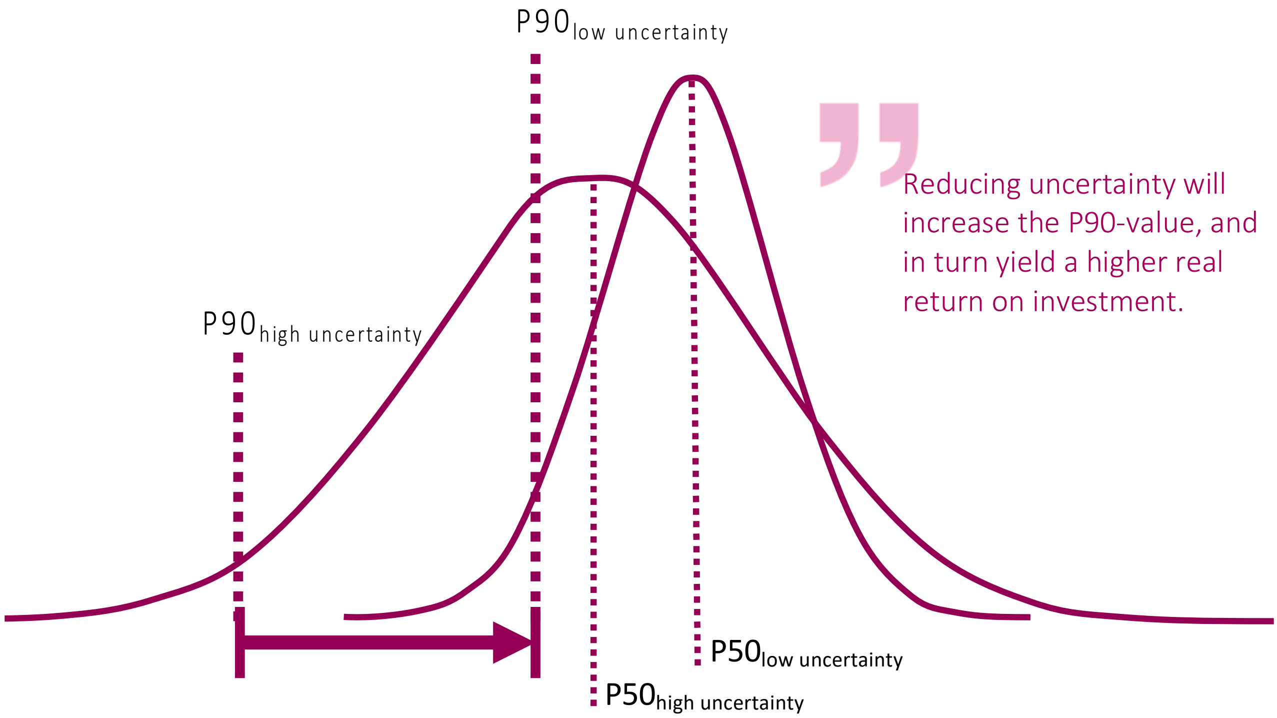
Introduction

As competition grows and margins decrease, reducing uncertainty of solar yield can be decisive. In a Purchase Power Agreement (PPA) auctioning bid, only projects that draw on an accurate assessment of projected energy yield can submit successful bids. On-site measurements are a powerful tool to reduce uncertainty of energy yields. Depending on financing terms, reducing uncertainty associated with less risk translates into a considerable increase in financial yield. Hence, the impact on a projects' key performance indicators and on the project value can be essential.

We identify that solar measurement campaigns accompanied with auxiliary measurements like wind speed, albedo, corrosion or soiling improve plant design and reduce capital risk in project development, construction, and operation. However, achieving high accuracy for solar resource and meteorological data by on-site measurements increases project development costs. From our experience in developing renewable energy projects worldwide, we have noticed the value of measurements receives low awareness. Based on the review of projects across the globe, expenditures for on-site measurements to leveraged project finance and project value show to already pay off for plant sizes in the order of 10 M.



"Reducing uncertainty will increase the P90-value, and in turn yield a higher real return on investment.

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About Suntrace

Suntrace was established 2009 in Hamburg, Germany's largest renewable energy cluster of firms. Today, Suntrace provides essential elements to develop renewable energy projects for clients all over the world. The range of services reaches from renewable energy resource assessments over owner's engineering to project implementation. In addition to full engineering, Suntrace also provides financial advisory and project development management. Having a portfolio of over 10 GW of installed solar in 150 projects over more than 50 countries, Suntrace with its strong team has established itself in renewable energy market. From concept to full realization, Suntrace has expertise in solar, wind and storage hybrid system with conventional power systems. Suntrace is part of Dornier Group with more than 2.000 staff in 18 locations across the globe.

Lowering Yield Uncertainty by Measurements Enables Financing

Solar resources account for a decisive share of uncertainty when determining the return on investment of large-scale photovoltaic power plants. For instance, yield predictions and yield certificates mainly comprise of three components: Technical plant specifications, solar resource evaluation and estimation of changes in energy yield over the lifetime of the system (Müller et al. 2017). It is proven that irradiance conversion models and uncertainty of incoming irradiance have the highest influence and subsequently meteorological data pre-dominantly affects plant performance (Müller et al. 2007). The required degree of solar data granularity can be adapted according to project progress, maturity, and budget. To get an idea of the cost-benefit relationship, it is important to discuss some basic mechanisms of uncertainty reduction in solar resource assessments.

For yield and return calculations, investors usually use the average, most probable solar resource conditions. These are typically described by the P50 value, which is defined as the value being exceeded with 50 % probability. Lenders rather rely on P90 values for their debt sizing i.e. the solar irradiance value that is expected to be exceeded to 90 %. Given that the P50 or mean value does not change substantially, more precise measurements will increase the P90 value.

The investor can demonstrate a higher cash flow to lenders, who, in turn, would allow a higher share of debt to the project, generally resulting in lower capital cost. Lender's may further reduce the Debt Service Coverage Ratio (DSCR) threshold or offer lower interest rates. All these yield a higher real return on investment.

A second effect of more accurate measurement is that the investor can price the bid in a Power Purchase Agreement (PPA) negotiation more accurately with lower risk deductions. Accordingly, the investor can price the tariff with a higher certainty on the solar fuel factor.
Several sources of uncertainty require such risk deductions. P50 values always differ between different measurements and this difference can be substantial. Further, the calculation of uncertainties itself is a source of uncertainty as is the difference in frequency distributions of auxiliary data[1]. Using not only multiple data sets but also adding the precision of on-site measurements allows reducing this risk deduction and in turn will lead to more favourable financing conditions and hence a change in real returns.
The depicted P90-effect assumes that the general estimate of a resource distribution is fairly accurate, indicated by an overall good overlap of resource distribution. Yet, the higher uncertainty associated with satellite-only data does not allow for more optimistic yield predictions. Opposed to that the Risk Deduction Effect assumes that without multi-source analysis and on-site data you cannot even be sure about the accurateness of the position of your resource distribution[2].

A thorough assessment in combination with high-quality on-site measurements may reduce an initial uncertainty of 10 % down to 2 % - and in turn will increase the P90-Best Estimate by roughly 2.5 %. Such an improvement may increase Net Present Value (NPV) by up to 200 kEUR each 10 MW.

[1] Calculations of one solar resource data provider and its implications refer to Bohny, Carl-Maria (2016), Photovoltaic Yield Assessment: Quantifying the Effects of Uncertainties on Key Performance Indicators

[2] The position of resource distribution is given by the P50 value. Depending on the region, satellite- i.e. modelled data potentially over- or underestimates the solar resource and with it the position of resource distribution.

Conceptual Phase

- Setup of SPVs
- Resource Mapping based on Modelled Data & Existing Ground Data
- Site Selection
- Outline Business Case
- Permits & Requirements

Pre-feasibility & Detailed Feasibility Analysis

Red-flag & Fatal-flaw Analysis of all relevant project details at high level. Iterative process – from rough to detailed:

- Solar- / Wind Resource Assessments: Modelled Data (long-term) and Ground Data (short-term)
- Techno-economic Optimisation
- O&M Concept
- Energy & Financial Yield
- EPC Market Cost Monitoring
- Feasibility Study Report
- Permitting – Tasks & Timeline
- Financial Concept (PPA Offtaker Validity)

Project & Site Qualification

- Geotechnical & Topographic Survey
- Environmental Impact Study
- Final Design & detailed Profitability Study
- Permitting
- PPA & other negotiations
- Land Agreement
- Modelled Data + Ground Data (> 1 year) of Solar - / Wind Resource

Equity & Debt

- Real Energy Yield & Operation Strategies
- Auctioning, select Equity Investors into SPVs
- Negotiating Debt Financing Strategy

Achieve low project risk through high-level assessments & reach higher NPV and IRR

Plant Operation

Monitor Plant Performance & optimise operation

Ground-based solar measurements are important at each phase of large solar power projects - from initial to financial close. Robust and well-maintained systems are recommended to be employed even throughout plant operations.

Ground-based Measurements during Project Development

For the development of utility-scale solar parks, there is an economic need for solar resource assessments for all phases of project development: At pre-feasibility phase, cost-efficient resources are exploited to estimate preliminary on-site conditions. Both private and public station networks for ground-based measurements may provide data of higher accuracy, regardless of the sampling resolution being not the same. Even initial phases benefit from existing ground-based measured data. To achieve reliable meteorological data, solar resource assessments rely on qualified satellite-derived solar radiation data validated by ground-based measurements (Ineichen 2014; Polo et al. 2016). To ensure highest cost-efficiency even at Pre-Feasibility Phase, knowledge on accessible information is a vital tool. At this conceptual phase, consultancy services may reduce uncertainty by analysing and comparing multiple available sources (Meyer 2010; Meyer et al. 2008) and thereby provide higher reliability to the resource distribution. Yet, one major source for uncertainty derives from the spaceborne data's coarse resolution: Data of low temporal and spatial resolution holds great potential for uncertainty. Consequently, the project's Feasibility Phase foresees the procurement of high-quality data after having gained first precaution.

The expansion of solar projects around the globe has increased the necessity of well-proven project development strategies. With these enhanced requirements, Due Diligence has shifted to the centre of attention of most lenders and project developers. To successfully pass Due Diligence for projects of this size, project developers must seek bankable expert opinion (McMahan, Grover, and Vignola 2013). The expert's assessment is required to consider risk analysis. For bankable expert opinions on meteorological conditions, data of lower uncertainty, significant representativity and higher time granularity is required to satisfy conservative approaches of banks and lenders. Thus, solar measurement campaigns are often carried out in this phase. As aforementioned, coarse temporal resolution is one source of uncertainty. Accordingly, measurement campaigns are recommended to provide data at minutely resolution. In order to carry out comprehensive risk analysis, meteorological i.e. irradiance data must encompass a full year of measurements.

The solar measurement campaign provides data of high quality to detailed profitability studies and a final plant design. Since even solar measurement equipment of highest standards may contain biased or distorted data, it is recommended to quality check all recordings. At best, consultancy services provide such documentation and post-processing of solar measurements as standardised procedure throughout the measurement campaign to enhance data quality and ensure representativeness of on-site conditions.

Having passed Due Diligence, the project reaches its construction and commissioning phase. Depending on the country-specific applicable regulations, weather monitoring is part of well accepted international health, safety and environmental (HSE) measures and best practices. On-site meteorological measurements bring an additional source of reliable information for Engineering-Procurement-Construction (EPC) companies. Benefit of monitoring of meteorological conditions can help on topics like pre-commissioning tests of equipment and systems. Warranty and insurance claims can benefit Investors, EPC or Local Supervision Authorities, when the decisive parameter is past or current weather condition. The low cost of operation of the solar monitoring station justifies the continuation of the measurement campaign, when compared to the benefits.

The best strategies during the operational phase rely on continuous monitoring of meteorological conditions and usage of forecasts to determine plant control. For the needs of plant control, both solar and auxiliary parameters are monitored. For instance, scheduled periods of solar field safety shutdowns are determined from wind speed monitoring and forecasting. Besides incoming irradiance and back-of-module temperature measurements, the monitoring of ambient temperature and relative humidity can explain performance deviations at solar field. Therefore, monitoring meteorological and auxiliary parameters helps to reduce the risk of malfunction and downtime (Chhatbar and Meyer 2011). Utility-size solar parks usually have at last two to three solar measurement stations distributed across the plant. Large PV plants aiming to fulfil Class A conditions for solar monitoring according to IEC61724:2017 are using even more stations to enable the plant's full potential and allow redundant surveillance.

Assumptions stated in this paper consider the financial benefit of solar measurement stations during plant development. Equipment that can be utilized beyond Due Diligence further increases the value of expenditures for measurement campaigns during project development. Sensitive sensors such as pyranometers will require re-calibration after approx. 2 years but may be considered for > 5 years of measurements. Therefore, it is worth investing in robust and durable equipment.

> Estimated 1σ uncertainty of the long-term average of GHI significantly decreases with ground measurements. Even basic measurement systems provide significant increase in accuracy.

Case Description Solar Resource Assessment type	Measurement Station Type[3] and Suntrace naming	Main Sensor	Geographical Situation related to Solar Resource Derivation from Satellite Data		
			Unfavourable	Average	Favourable
No Adaption to Measurements	No station	Satellite only	8.0%	5.0%	4.0%
Basic Measurement Station	Tier 3 alpha	High-quality Pyranometer	4.0%	3.5%	3.0%
Advanced Measurement Station	Tier 2 phi	High-quality Pyranometer + RSI	3.5%	3.0%	2.5%
Research-grade Measurement Station	Tier 1 omega	Sun Tracker, high-quality Pyranometer + Pyrheliometer	3.0%	2.5%	2.0%

[3] According to World Bank ESMAP.

Guidelines for Solar Measurement Campaigns

The World Bank's Sector Management Assistance Program (ESMAP) first introduced a classification system for measurement stations in support of solar energy projects. The classification ranges from high precision Tier 1 stations to more affordable Tier 2 and lower cost Tier 3 stations. Tier 1 stations require an expensive sensitive solar tracker, at least one pyrheliometer for highest accuracy Direct Normal Irradiance (DNI) and shaded plus unshaded pyranometers for measuring Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI) respectively. Tier 2 stations are equipped with a Rotating Shadowband Irradiometer (RSI), which is delivering also all 3 solar radiation components GHI, DHI and DNI. Tier 3 stations do not have moving parts and only provide the key for PV, which is GHI. Suntrace station types from alpha to omega refer to the presented WB Tier classification. Having incorporated ventilated and heated pyranometers, our stations exceed World Bank requirements. With Suntrace measurement solutions, such Class A[4] pyranometers are provided even with Tier 3 station types.

For Concentrating Solar Power (CSP) or Concentrating Solar Thermal (CST) systems, Tier 1 and Tier 2 stations are required[5] as these station types provide DNI measurements. For conventional PV projects, regardless of the foreseen PV module technology, all three tiers may be considered. For tracking PV technology and bifacial PV, Tier 2 stations are of benefit, because the RSI provides also measurements of the diffuse irradiance DHI, which has higher effect on the yields of such PV systems.

For Floating PV, the measurement of irradiance on buoys or floating platforms can be challenging. Tier 1 stations mounted on the water would require very stable platforms to reach the required tracking accuracy. Even Tier 2 and Tier 3 stations should remain as horizontal as possible, minimizing disturbance by waves. A practical solution is commonly to measure irradiance at the shore and auxiliary parameters offshore[6]. For such onshore measurements, again all 3 tiers can be considered.

Generally, the most feasible tier is moreover defined by the project site: High maintenance requirements of Tier-1 type favour Tier-2 and Tier-3 station's for remote areas.
For all technologies and tiers, it must be ensured that the stations are well-maintained and equipped with high-quality pyranometers[7]. Furthermore, it is advisable to consider low-cost photodiodes for redundancy and regular quality checks. To capture the full meteorological year, ground-based measurements are recommended to continue for at least 1 year (12 months). Given project development often faces very limited time, ground data of at least 3 months can be considered to improve initial solar resource estimates. To avoid further potential delay, on-board calibration of instrumentation can greatly benefit the project's economy of time[8].

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[4] Class A according to IEC61724:2017.

[5] Classification of Solar Measurements for CSP according to World Bank.

[6] Buoys enable the measurement of e.g. water temperature, wave motion and wind speed. The measurement of such auxiliary parameters commonly gives proof to a higher efficiency due to the cooling effect of the underlying water body.

[7] According to IEC 61724-1:2017 Class A-C International Standard for Photovoltaic System Performance.

[8] Redundant measurements enable in-situ calibration of Tier-2 stations. By this, delivery time can be reduced by 6 weeks.

Suntrace Solar Resource Services

For PV, floating PV & CSP yield, the strongest impact on uncertainty originates from solar resource uncertainty. During the early stages of project development, the solar resource uncertainty of an initial estimation can reach 10 % and more. Through our step-wise approach by assessing multiple satellite sources for long-term best-estimates and considering highly accurate ground-based measurements, we significantly reduce this uncertainty. In turn, this mitigative approach establishes a reliable and trustworthy base that is crucial for bankability and investment of the project. A thorough assessment in combination with high-quality on-site measurements may reduce uncertainty down to 2 % - and in turn will increase the P90 best estimate by about 2.5 %. Such an improvement may increase Net Present Value by up to 200 kEUR each 10 MW. By offering both on-site measurement campaigns and independent SRA, Suntrace is your ideal partner for all activities related to your project.

✓ Site Screening & Selection

✓ Solar Resource Assessments

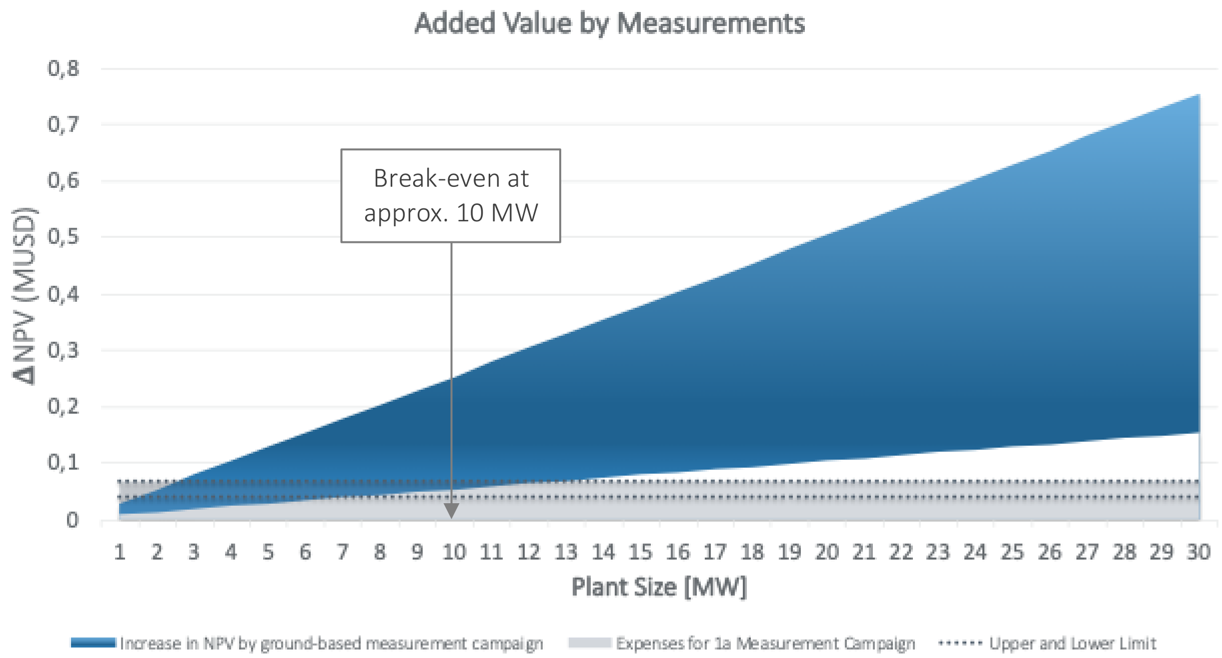
✓ On-site Measurement Solutions

Quantifying the Value of Measurements

Using Key Performance Indicators (KPIs) such as Internal Rate of Return (IRR) or Net Present Values (NPV) enable reliable cost-benefit analysis of CAPEX investments such as solar measurement campaigns. Among our projects, we can indicate a clear upward trend in NPV due to advanced resource and risk assessments. By following a stepwise approach, the increase in NPV results in up to 40 %. The expenditures for 1-year measurement campaigns range from approx. 45 kUSD to 80 kUSD [9].

Overall, it can be said that a higher tier of measurement equipment directly translates into higher accuracy and subsequently into a higher increase in NPV. This behaviour can also be seen in the figure below, where the blue-shaded area indicates the expected increase in NPV by ground measurements. The underlying financial model assumes tariffs according to 20-year PPAs [10]. To its first order, the wide-spread in ΔNPV is driven by the magnitude of solar resource and the accompanied accuracy i.e. tier of measurement equipment. Deducted by the expenditures for a 1-year campaign (red-shaded area), solar measurements already pay off for plant sizes above 10 MW. For regions with high solar resource, this threshold can move to even smaller plant sizes. With the efforts of such high-level risk assessments, developers ease their financial negotiations by providing testified, bankable evidence on ground conditions, providing comfort to lenders and investors.

> Expenses for 1-year measurement campaigns ranging from approx. 45 to 80kUSD define the break-even point as of which the return exceeds the CAPEX investment. Increase in NPV by ground-based



> measurements show measurements to already pay off for plant sizes above 10 MW.

[9] Including expenses for station maintenance of accessible and prepared sites.

[10] Exemplary tariffs considered in financial model: Mexico 20USD/MWh, Vietnam 30USD/MWh and Germany 40USD/MWh.

Venturing Measurement Campaigns to its Fullest

Whilst irradiance is the predominant driver in energy yield, it has already become standard to extend campaigns by the measurement for auxiliary parameters. Compared to the effort of commissioning and maintaining high-quality meteorological instruments, the additional benefit that soiling-, wind- and corrosion sensors bring to plant design, come at low cost. In the field of service life and damage analysis, the assessment of corrosivity investigates the quality and aging behaviour of solar field components and supporting structures, as well as their construction materials and individual plant components. Here, service providers draw on an extensive wealth of experience from the analysis and evaluation of numerous cases of damage from practical field application[11]. With high-level corrosion assessments, both plant design and subsequently plant lifetime are optimized, CAPEX requirements are sharpened during project development and the risk of technical failure during operation and warranty period is reduced.

Soiling directly affects energy yield by reducing insolation by up to 20 % within one month [12]. Especially arid and desert areas suffer from severe soiling. To overcome this, frequent cleaning of solar panels is necessary. At utility-size power plants, cleaning efforts are a main factor to OPEX and thereby stress the need for optimizing cleaning practices. Soiling sensors enable the assessment of expected soiling impact to any plant size and design during project development and enable the optimization of cleaning cycles during operation. Qualitative evaluation of soiling during the solar measurement campaign, like records of visual aspect, physical consistency at sensor's cleaning and colour, can benefit the selection of the cleaning philosophy.

Addressing both plant lifetime and OPEX, high-level solar resource assessments accompanied with auxiliary measurements hold great potential to enhance project revenue. The combined uncertainty of lifetime energy yield amounts to approx. 8 %. Within this uncertainty, solar resource assessment and changes in system performance provide the highest share (Müller et al. 2014). In conclusion, solar measurement campaigns offer improvement to a solar project's most vulnerable sources for risk and therefore must be seen by project developers as valuable tool.

Takeaways

Both our experience and the financial model show optimization of utility-sized solar power plants using meteorological data of highest possible accuracy to be indispensable. Often, many cost-relevant decisions are taken based on rough guesses (Reise et al. 2018). On-site measurements enable objective decisions, quantified by key financial parameters leading to both highest success during project development and maximum revenue during operation. Without high-level solar resource assessment, the possible range of deviations of economic key figures is too large and may lead to severe losses or unfavourable financing conditions, within a competitive market environment. Compared to risk reduction and their impact on economic key figures, investment in meteorological on-site measurements are small and should be considered for any utility scale solar power plant. The additional CAPEX for such measurement campaign proves to pay-off for plant sizes as of 10 MW.

[11] The assessment shall comply at least with ISO 9226:2012 and ISO 8407:2009.

[12] Based on measurements of Direct Normal Irradiance.

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Member of Dornier Group

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