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# EXPERIENCE, GRID INTEGRATION AND SHADING 25 YEARS OF TECHNOLOGICAL AND ECONOMICAL LEARNING IN PV SYSTEMS WHAT ARE THE FINDINGS ON THE TECHNOLOGICAL AND ECONOMICAL SIDE FOR ONE GENERATION OF PV APPLICATIONS?

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**ABSTRACT:** Long time experience by TNC Consulting over 25 years on design and operation of PV plants is used to look back on technological, economical and performance development and give an outlook on possible future challenges. The point of view of a system engineer is stressed, trying to take into account not only upfront costs and gains, but also performance over time and operational costs and developments. Longtime data is presented for exemplary PV plants as well as clustered data over a larger amount of more recent PV plants and a shorter period of time.

Overall performance and yield is analyzed in absolute numbers, development over time for exemplary PV plants (back to 25 years) and in a cross-section over numerous plants for more recent PV plants, allowing for possible outlooks on future development. Cost structure of PV systems over 25 years shows a strong decrease in BoS as well as module and inverter costs, but also an increase for BoS in present PV plants. In order to reduce overall PV system costs, BoS costs must be understood correctly and reduced for future projects. Specific aspects from technological development are highlighted and their influence on overall performance and LCOE is assessed.

Keywords: PV systems, long-time performance, yield, LCOE, BoS

## 1 PURPOSE OF THE WORK

TNC Consulting has 25 years of experience in planning, building and operation of PV plants, with a focus on performance. The combination of an independent system engineer with experience as PV system operator allows for an overall view on technical as well as economical developments over a longer timespan. The findings from experience shall be used to give a possible outlook on future chances and challenges for PV industry.

## 2 APPROACH

Based on the learning curve for PV plants with direct participation of TNC and data available from other tasks such as IEA-PVPS different aspects are described using examples from PV plants over the whole time period. Improvements on technical, economical and operational side are described with exemplary numbers. An overall view on system performance is given, rating and comparing the influence of different of the described aspects over the time period of 25 years as well as for future PV plants. The focus lies on the essential market segment of small to medium rooftop PV systems.

## 3 RESULTS

### 3.1 OVERALL COST DEVELOPMENT

Based on the detailed information available on costs for PV systems over all different components, TNC has maintained a learning curve over 25 years for PV plants in Switzerland (Fig 1).

While cost reduction in absolute numbers is very impressive at over 90%, the shift of the shares of the main components of PV system costs PV Modules, Inverters and BoS is no less interesting. Especially the BoS costs are worth a closer look for overall cost

optimization. Their share has increased once again over the last few years for the PV plants analyzed. While falling from initially above 50% of overall system costs to below 10% of overall system costs for the time with high module costs around 2007, BoS share has increased again to values of almost 50% again for small to medium PV plants (Fig 2).

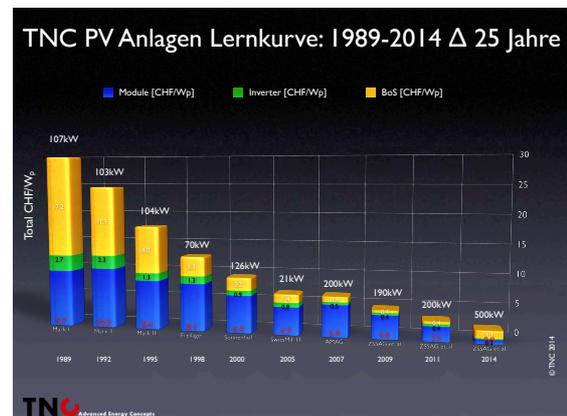


Fig 1: Overall PV system prices in 25 years of experience

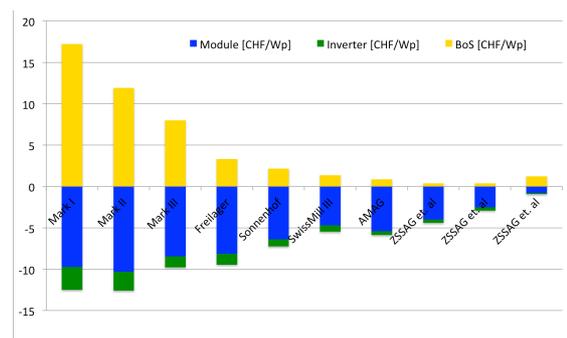


Fig 2: Overall PV system prices with focus on main

components PV modules, inverters and BoS

### 3.2 BOS COST DEVELOPMENT, ANALYSIS

BoS costs have not only had a hard time keeping up with module price development, complexity of PV projects has changed over time. While the first PV plants had pilot and pioneering character and needed very thorough planning and guidance, PV systems got more standardized in technical terms and better accepted in terms of handling in certifications and approval processes, reducing the share of BoS and focusing on hardware (module and inverter).

With PV reaching higher penetration rates and focus of discussions on energy systems moving from PV plants as “standalone” solutions toward system integration (grid integration, grid safety, power consumption) as well as a raised perception in non-energy-related authorities (i.e. building owners, insurances, security and approval bodies), requirements for PV systems in Switzerland have risen, especially on the non-PV front. Examples are working security on roofs, additional documentation for insurances and authorities, more complex legal needs for contracts and others. All these facts add to the extent of BoS. A more detailed analysis of BoS Costs shows this growing complexity.

### 3.3 SYSTEM PERFORMANCE AND YIELD OVER 25 YEARS

Performance and yield of an exemplary PV plant is analyzed over the period of time of 25 years with a focus on developments over time. Some of the technological developments in module and inverter design are highlighted in comparison to state of the art technology.

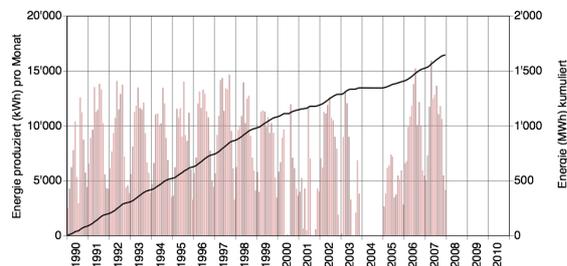


Fig 3&4: Pilot and demonstration PV plant from 1989 on a highway noise barrier in Switzerland providing long time performance data over 25 years+. The early states are very well documented thanks to P&D projects.

For performance and yield analysis of more recent PV plants, a broader set of data for PV plants in Switzerland is evaluated on a higher time resolution. This allows a more detailed analysis of the spread of values on performance for a shorter period of time.



Fig 5: Exemplary PV plant from a clustered set of small to medium size PV plants realized 2014/2015 with state of the art technology, which are being integrated into the existing dataset up to 2014.

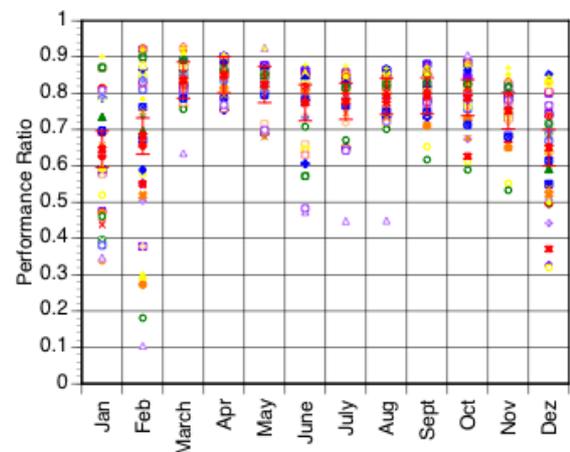


Fig 6: Performance ratio over several PV plants on a monthly base.

Visible effects in Fig 6 on performance ratio include during winter snow on modules, stronger local shading due to low elevation angle of sun, etc. while reduction in summer is probably due to components failure.

### 3.4 TECHNOLOGICAL DEVELOPMENT

Solar cell technology has evolved permanently, leading to the well-known and appreciated quality of PV products. Cell size for example has increased from 4 inch to 6 inch standards. Unfortunately, cell technology has evolved so fast, that it is already difficult to impossible to get spare cells/modules for PV plants older than 15 years which make a good electrical fit. This could become a major issue in the future if the amount of PV installed today once needs refits.

The same is true for refits of inverters to “old” PV plants, since the PV plant design at time of construction may not be done using state of the art layout. Electrical properties such as voltage range and currents of “old” PV plants may no longer be compatible with state of the art inverters or at least restrict the range of products suitable without adaptations in layout/wiring.

Developments in mounting systems have led to faster installations with a higher grade of standardization. Cost pressure also led to many mounting systems on flat roofs with low tilt angles and almost no space above roof surface (wind load optimization). The lower tilt angle

results in faster soiling which leads to higher maintenance costs. The closeness to the roof surface leads in snowy regions such as Switzerland to accumulations of snow at the lower end of the module instead of allowing the snow to slide off. In addition, aggregated snow takes longer to melt. This reduces production in winter, where electricity is potentially more valuable than during summer midday time.



### 3.5 INFLUENCE ON OVERALL PERFORMANCE AND LCOE

While technological development has led to large reductions in up-front costs of PV systems, some of the developments have led to potentially higher maintenance and lower overall performance. Both of these facts influence operational costs of PV plants directly.

Levelized costs of electricity (LCOE) consist basically of capital costs and operational costs. While capital costs have decreased drastically, operational costs have decreased only slowly. This leads to a higher share of operational cost of up to 30% in LCOE for small to medium PV plants.

Cost pressure on PV system components, especially in the area of BoS, can lead to reductions in overall performance of PV systems. At the same time, operational costs increase. This slows down further reduction of LCOE. System planners and operators as well as installing companies should focus more on the lifecycle costs, not only for integration in energy systems but also for further reduction of LCOE.

## 4 CONCLUSIONS

- Share of BoS on system costs is rising, partly due to fast reduction of hardware costs and partly due to new requirements and certifications needed.
- Focus on upfront costs of PV systems can lead to neglecting of operational costs. At the same time the share of operational costs on LCOE increases.
- Cost pressure on components and especially installation time can lead to system imminent performance reduction.
- For future LCOE optimization, BoS and operational costs will pose main challenges.
- Risk of quality reduction of installed PV systems rises with too high pressure on costs, especially on BoS elements.
- Well-engineered PV plants show good performance and yield over more than 25 years of real operation with very little decrease, even without high

maintenance.

- Average PV system performance has increased, but realized PV plants show large deviations in performance.

## 5 OUTLOOK/WORK IN PROGRESS

Performance and yield analysis is updated and expanded by a larger amount of PV plants in Switzerland for even more reliable data and conclusions.

BoS cost analysis is developed more in detail to better understand the change in the share on overall system costs.

Detailed analysis of performance and evaluation of possible correlations to singular events is carried on.

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