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PHOTOVOLTAIC MARKETS & TECHNOLOGY

HARVEST POTENTIAL

While new designs and components are opening agricultural operations to PV development, the future and viability of agrivoltaics is far from assured


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A question of priorities

With investors having to make decisions around tilt angle, row spacing, module type, substructures, and many other parameters for ground-mounted solar, Johannes Linder, director of system design and innovation for German engineering, procurement and construction (EPC) services company Belectric, considers the optimal approach to PV system design.

To build a ground-mounted PV system, large volumes of a small number of components are needed. Parameters that affect plant design, including row spacing and tilt angle, are defined once – as are modules – then scaled.

That suggests small component and design-parameter changes can have a large effect on system cost and yield. In addition to technical cost optimization, replacing module clips with direct screw connections, for example, it is primarily yield-relevant components and the design parameters that offer corresponding adjustments.

There are more variants of ground-mounted system than you may suspect. Tilt angles might range from 10 degrees to 25 degrees, row spacing from 1 meter to 5 meters, and DC to AC ratios from 1 to 1.8. Various substructures and orientations may be suitable – south facing or east-west, portrait or landscape. Multiple module types and sizes may be considered, with wafer format varying from 182 mm tunnel oxide passivated contact (TOPCon) panels to 210 mm TOPCon or heterojunction solar.

A five-digit range of system designs quickly arrives, requiring strenuous analysis using different kinds of modeling and simulation software.

Photo: Engie Laborelec

Accurately measuring on-site data, as well as inputting all cost parameters, is crucial to the modeling and simulation that determine optimal system design.

Big question

When optimizing system design, the key question is: What is the objective? Levelized cost of energy (LCOE) is frequently the response, but that focuses on cost optimization rather than expected revenue. It may be worthwhile tolerating more shading than LCOE calculations suggest, to realize more kilowatt-hours of generation per square meter. That could mean higher generation cost. But if revenues higher than the cost of generation can be secured, the trade might pay off in the long run.

At revenue of €0.10 ($0.11)/kWh, maximizing generation capacity per square meter is optimal; at €0.05/kWh, the specific yield per installed kilowatt of generation capacity is more important. LCOE calculation will miss the distinction and Belectric considers LCOE's inclusion as a key performance indicator irrelevant to investment decisions.

Area trap

Faulty optimization approaches – rather than objectives – can lead developers into the "area trap."

General electricity production studies tend to compare tracker-mounted solar installations with ground-mounted projects of the same generation capacity, even though tracker-mounted panels tend to require more land. They effectively assume that an infinite amount of land is available and a price per hectare for the nominal site is then assigned, with the tracker installation then incurring higher leasing costs because of its larger land requirements.

In the real-world development process of ground-mounted facilities, of course, things are often different. The project developer secures as large an area as possible and then considers which system design they would like to implement. The area is therefore given and not variable.

Accordingly, when comparing system designs, tracker systems that realize an output in the range of 11 MWp for a given area, and a certain row spacing, should actually be compared to fixed-mounted systems that would actually have a generation capacity of around 16 MWp on the same area. Even though the specific yield of the tracker plant is higher, the fixed-mounted plant generates more electricity in absolute terms.

The result when considering the real case differs significantly from the former comparison, which calculates a tracker plant that has the same output as the fixed-tilt plant, and which merely requires more land.

The additional lease cost that would be required has less of a negative impact on the economic analysis than the fact that significantly fewer kilowatt-hours will be generated in absolute terms if a decision is made for trackers. Caution is therefore required here, especially when transferring general analyses to project-specific optimizations.

Targeting conflicts

We can also consider the metrics that investors typically use to evaluate future cash flows, such as those found in profitability analyses of ground-mounted plants. These are not the cost of electricity but net present value (NPV) and internal rate of return (IRR). NPV represents the value of future revenue at today's prices and IRR indicates the rate of return beyond a project's break-even point.

In this context, it is worth mentioning special characteristics of ground-mounted plants that have a great influence on the two ratios. Assume we have an area of 10 hectares available and can build on it without technical restriction. The first question is whether to use a tracker or a fixed system with south or east-west orientation. The possible investment volume ranges from around €9.4 million, for a tracker project at 11 MWp of generation capacity, to around €11.3 million for a plant with a fixed-tilt system, at 16 MWp. There is a wide, viable range in between that allows for the system design to be tailored to a specific business case.

The relatively large difference in potential investment volume means that there is often a conflict between achieving the highest possible NPV and the highest possible optimal return on investment. In other words, with one system design, the NPV of the project would be higher but the IRR would

"It may be worthwhile tolerating more shading than LCOE calculations suggest"

Summary of the economic impact of innovative system designs

Optimized standard design	- still the most profitable solution - see table on pp. 54&55
Biodiversity open space facility	- slightly higher costs for biodiversity measures - row spacing: simplified assumption of at least 4 meters - NPV decreases by 11% in the example compared to the standard design (-€700,000 compared to the optimal solution, see table on pp. 54&55)
Single-axis tracker designs with one or two modules	- higher specific costs (€/kWp) than in the standard design. - higher market value for generated solar power, of €4/MWh - see table on pp. 54&55 for the optimal variant
Agrivoltaic with tracker	- slightly higher costs than standard tracker for measures relating to erosion, soil protection and water management - distance between trackers at least 10 m - assuming lease costs 85% lower than those of an open space facility, the NPV is around 14% lower (-€900,000)
Optimized vertical module mounting	- lowest cost, but also lowest output per m^2 - higher market value for generated solar power, of €8/MWh - economically worst variant (excluding agrivoltaics) - NPV is 53% below optimal variant (-€3.5 million)
Agrivoltaic with vertical module mounting	- row spacing at least 9 meters - higher market value for generated solar power, of €8/MWh - economically worst agrivoltaic variant (excepting high elevation with semi-transparent modules) - NPV is 56% below optimal variant (-€3.7 million)
Agrivoltaic with very high elevation	- 4 meters in height - highest cost/kWp - German renewable energy law agrivoltaic bonus of €10/MWh - assuming lease costs 85% below those of a ground-mounted system, NPV is around 17% below optimal variant (-€1.1 million) - if semi-transparent modules are required (20% transparency) to reduce shading, then NPV is 58% below the optimal variant (-€3.8 million)

Ranking*		System characteristics					
After NPV	After IRR	Module mounting	Pitch***	Row spacing	DC/AC	Base area according to building regulations	Overall height
1.	2.	Fixed-tilt, south facing, four in portrait, 10°	10.45 m	1 m	1.15	0.77	2.37 m
2.	2.	Fixed-tilt, south facing, three in portrait, 10°	8.083 m	1 m	1.15	0.74	1.95 m
3.	3.	Fixed-tilt, south facing, four in portrait, 15°	10.769 m	1.5 m	1.15	0.73	3.18 m
4.	1.	Single-axis tracker, single module in portrait	3.882 m	1.5 m	1.1	0.52	2.48 m

This analysis by Belectric reflects considerations of a real project from 2022, but general statements, especially considering the current market environment, cannot be derived from it. The calculation is based on the realistic case that the area is fixed at 10 hectares and that bifacial n-type TOPCon M10 modules and string inverters are used. For NPV calculation, the expected IRR (see text) was used for discounting and no debt capital was considered. For operating expenditure, discounted annual values were added.

be lower. With another, a lower NPV would result in a higher IRR. In such cases, Belectric is guided by customer priorities but recommends optimizing NPV. One advantage of this approach is that NPV is methodologically more reliable as well as more robust to changes in total investment cost.

NPV or IRR?

Consider the two parameters using the example of a typical project optimization exercise from last year. Construction began at a 10-hectare site in southern Germany at the start of 2022. The assumption was that the electricity generated would be sold for 10 years under a power purchase agreement (PPA) for €0.09/kWh and then sold according to forecast electricity market price curves. The investor's expected rate of return – the "hurdle rate" for the investment decision – would be 3.5% for the first 10 years then 5% for years 11 through 30.

Photo: KU Leuven

Advancements in technology, as well as new applications for PV such as agrivoltaics, mean a wide range of system designs and business models can now be considered for a given site.

The system design that yielded the highest IRR, based on those assumptions, was the tracker. By contrast, a land-efficient, flat southern-facing system would have yielded a significantly higher NPV. In the first case, the return on capital employed is higher; in the second case, more capital can be invested profitably.

Deciding which option made more sense partly depended on the investment alternatives the customer had for their capital. The differences can be significant, depending on project-specific set-up and business case assumptions. In this case, if the customer had opted for a tracker system, promising the highest IRR, the NPV of the project would have deteriorated by almost €700,000. That corresponded to a deterioration in NPV of around 10%.

With the various PV system designs established on the market, it is possible to optimize the business case via the specific yield, specific costs, and investment volume. This is a lever that is not taken into account when specific parameters are considered in isolation, which is another reason why Belectric recommends looking at the NPV of all relevant system design combinations for each project.

One advantage of IRR that is often cited, is that the difficult-to-determine discount rate needed to calculate what future cashflows represent in today's prices is not required as an input. Belectric believes that it makes more sense to look at the sensitivities of different discount rates rather than focusing on a pure IRR consideration.

Nevertheless, it is conceivable that in certain cases, a focus on consistently optimizing IRR does indeed make sense. This could be the case, for example, with citizen investment schemes or community solar, where the investment is spread between many small investors and where profit in absolute terms is less important

Output and yield			Costs and revenues				Key perfomance indicators		
Nominal power	AC power	Specific yield per year	capex**	capex/ kWp**	opex**	Costs and revenues**	Return IRR	Net present value (NPV)	Net present value deviation**
16.837 MWp	14,641 KVA	1,107 kWh/kWp/a	Reference	Reference	Reference	Reference	8.88 %	6,657,615 €	Reference
16.326 MWp	14,196 KVA	1,120 kWh/kWp/a	-241,013 €	10.6 €/kWp	-92,190 €	-447,508 €	8.88 %	6,543,310 €	-114,305 €
16.339 MWP	14,207 KVA	1,120 kWh/kWp/a	-196,490 €	12.7 €/kWp	-89,912 €	-422,339 €	8.86 %	6,521,678 €	-135,937 €
11.331 MWp	10,301 KVA	1,334 kWh/kWp/a	-2,162,307 €	202.7 €/kWp	-652,165 €	-3,485,492 €	9.14 %	5,986,596 €	-671,018 €

** In total, Belectric has calculated more than 10,000 system designs. The table printed here shows the top three by NPV ranking as well as the top system by IRR ranking (tracker design).*
*** The values for capex, capex kWp, opex, costs and revenues, and net present value deviation refer to the deviation from the first-placed system design combination (reference).*
**** The pitch denotes row spacing, measured from module leading edge to leading edge. Row spacing denotes the gap between the trailing edge of the module and leading edge of the next row.*

than returns for individuals. Belectric leaves such considerations to customers.

Input parameters

The central elements of any modeling and simulation approach are the input parameters. If these are incorrect, no trustworthy NPV or IRR values can be calculated. In addition to the parameters related to the business case – PPA or subsidy tariff, discount rate – the market values, the expected yield and, of course, the costs for all system design combinations, should also be considered.

Within the system design variants and the corresponding generation profiles of ground-mounted PV plants, different market values can be obtained. It is assumed that a tracking system or a vertical east-west system will achieve higher market values, on average, due to their broader generation profile. This is because the targeted addition of solar power will continuously increase the oversupply of solar power at midday, when all the systems that face south are feeding maximum power into the grid at the same time while the sun is shining.

In the yield simulation, care must be taken to ensure that the pan files – text files representing module performance that are used in PV modeling – do not provide unrealistic inputs, especially when comparing different module types. For this, a "pan file sanity check" is worthwhile.

Cost inputs are also crucial for simulation. To get a holistic picture, the associated transport, installation, balance of system, and operations and maintenance (O&M) costs should each be considered, in addition to the cost of the main components. As an EPC company, we are in the comfortable position of being very close to the market since we purchase all components, as well as all services, ourselves. We also take care of O&M at plants.

Experience matters

For years, we have worked with a diverse range of modules, both in terms of dimensions and cell technology. Having a large selection is challenging but, on the other hand, it increases optimization potential.

> *"It's possible to optimize the business case not only via the specific yield and specific cost, but also via investment volume"*

Diversification is also emerging in the area of substructure types. Agrivoltaic or biodiversity systems come with a variety of new substructure types which are also continuously monitored and analyzed by Belectric (see table above). The resulting analysis effort is worthwhile because, for example, you can quickly see that agrivoltaic systems with trackers are becoming more prominent in Germany. System design optimization of ground-mounted PV systems does not provide black-and-white results, but for all those who are clear about their optimization goal, the potential is immense. pv *Johannes Linder*

About the author

*Belectric's **Johannes Linder** previously served as an international project manager for utility-scale projects in Europe, Australia, and India. He has worked for several startups and developers in the industry and is certified as a PV expert by TÜV Rheinland.*