Heliostat Innovation in Detail to Reach Challenging Cost Target

Andreas Pfahl[1, a)], Hicham Bouzekri[2], Abdelali Djdiaa[2], Daniel Benitez[3], Vincent Nettelroth[1], Jens Rheinländer[4], and Andreas Krause[4]

[1] German Aerospace Center (DLR), Institute of Solar Research (SF), Solar Power Plant Technology, Professor-Rehm-Str. 1, 52428 Jülich, Germany.
[2] Moroccan Agency for Sustainable Energy SA (Masen), N°50 Rocade Sud, Rabat-Casablanca, Immeuble A-B-C-D Zenith, Souissi, Rabat, Morocco.
[3] DLR, SF, Qualification, Paseo de Almería, 73-2°, 04001 Almería, Spain.
[4] DLR, SF, Solar High Temperature Technologies, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany.

[a)] Corresponding author: Andreas.Pfahl@dlr.de

Abstract. To be able to achieve the challenging cost targets for heliostat fields, several innovations in detail for a carousel type heliostat were developed. The resulting cost reduction and local content are estimated. First conclusions from a Moroccan-German project that aims to increase the local added value of heliostat production are drawn.

INTRODUCTION

At SolarPACES 2011 heliostat, field cost of 75 $/m² were claimed for the present year 2020 to keep CSP cost competitive [1]. Six years later, at SolarPACES 2017, a heliostat concept was proposed already in close reach to this benchmark [2]. First tests validated the technology concept [3]. Now, with the presented further innovations in certain parts of the design, the cost target seems to be well achievable.

Additionally, the local production share is significantly increased. This is quite relevant since the high possible local production share of CSP is probably the most important advantage compared to PV, besides better dispatchability of course. Several studies show that a local content of more than 60 % is possible for CSP (e.g. [4]). However, the realized local content is often much below this value so far. For the NOOR solar power plants in Ouarzazate 35 % were realized for instance [5].

To reach the cost and local content targets for the heliostat field, innovations of all the four main components of the heliostat were found: The concentrator, the azimuth and elevation drive, and the foundation (Fig. 1). The impact of these innovations on the cost and the local content were estimated. A high local content of heliostat production is the purpose of the HelioMaroc project which will be also shortly presented.

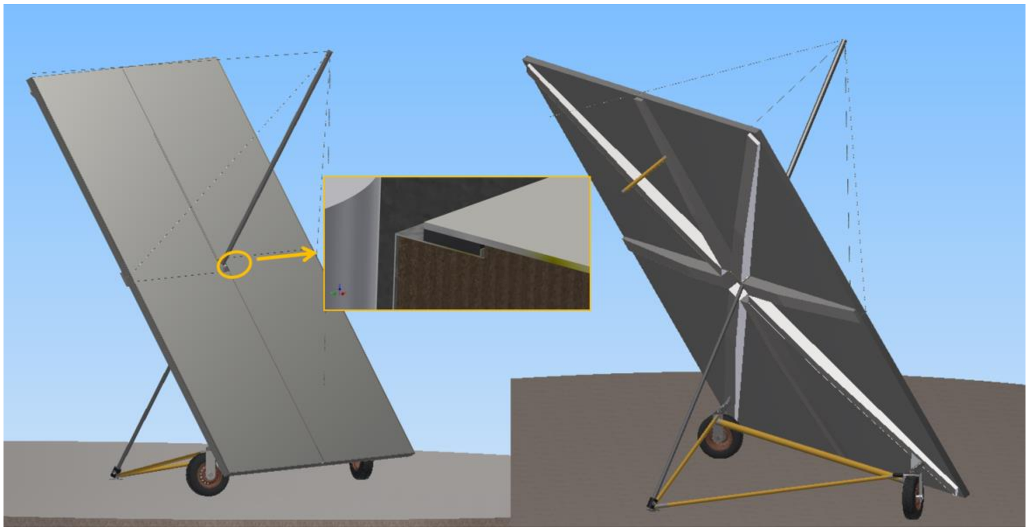

FIGURE 1. Carousel heliostat with innovations to reach cost target

INNOVATIONS

Sandwich Concentrator

The concentrator (mirror panel) accounts for about 40% of the heliostat costs. It is therefore particularly important to reduce its costs. In the SAHEL project, a sandwich concentrator with polyurethane core is under development. Due to the full surface support of the mirror and the resulting high shape accuracy and due to the lower absorptivity of the thin glass mirrors, an increase in energy yield of 5 % is expected [6]. The low number of individual parts is also favorable.

Initially it was planned to manufacture the concentrator as a monolithic unit to avoid the time-consuming alignment of individual facets (canting) [2]. However, cost analyses of different manufacturing approaches showed this is not economically feasible with the planned sandwich concept. The main reason are the very high forces the mold for the concentrator would have to resist. They result from the pressure of the foam on the mold during foaming in combination with the targeted large area of 30 - 50 m² of the monolithic concentrator and of the mold. This would lead to very high mold costs. Therefore, smaller sandwich facets are now manufactured and connected to sandwich cantilever arms.

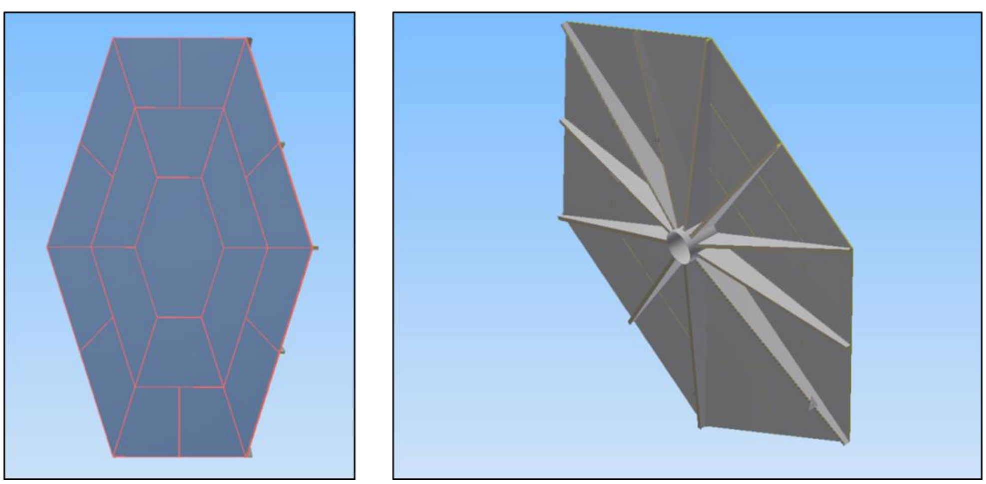

FIGURE 2. Concentrator with sandwich facets and sandwich cantilever arms, both with polyurethane core

A reduction of the forces during foaming can be achieved by reducing the surface area and also by reducing the pressure. No back pressure at all would occur with preformed foam cores. However, additional bonding of the back steel layer and the front mirror layer to the core would be required with additional costs. On the other hand, this would open the possibility to use other material for the sandwich core. Cardboard honeycomb would be particularly favorable because of its very low cost [7]. Another advantage of this material is its low volume when folded. Up to now, this has not been pursued further, particularly due to the very high sensitivity to moisture or the high costs of impregnating the material [8]. However, currently new approaches are investigated which may lead to a cost effective solution.

Azimuth Drive

Wheels and friction drive

Due to the low speed, disused car wheels are suitable for the carousel's carriage. This "upcycling" reduces the CO_2-footprint and enables extremely low costs. Size and load capacity match well with the cost-optimal heliostat size of 30 - 50 m². By using adapter plates, different wheel types can be used. Pressure loss occurring over a longer period of time would be compensated by the cleaning and maintenance personnel. Since the flexing work increases with falling pressure, the energy consumption per distance can be used to determine the tire pressure and to monitor it without additional sensor. The wheels are largely protected from direct sunlight by the concentrator (Fig. 3) which extends their life time. If a tire change becomes necessary, it can be done e.g. during bad weather periods. In the SAHEL project it will be investigated whether the car wheels are suitable for a friction drive (Fig. 3). By this, the chain gear stage of the previous solution [2] with the relatively expensive chain wheel and chain housing could be avoided. Another advantage results from the large diameter of the wheel which leads to a higher gear ratio and reduces the required torque of the gear motor and its cost.

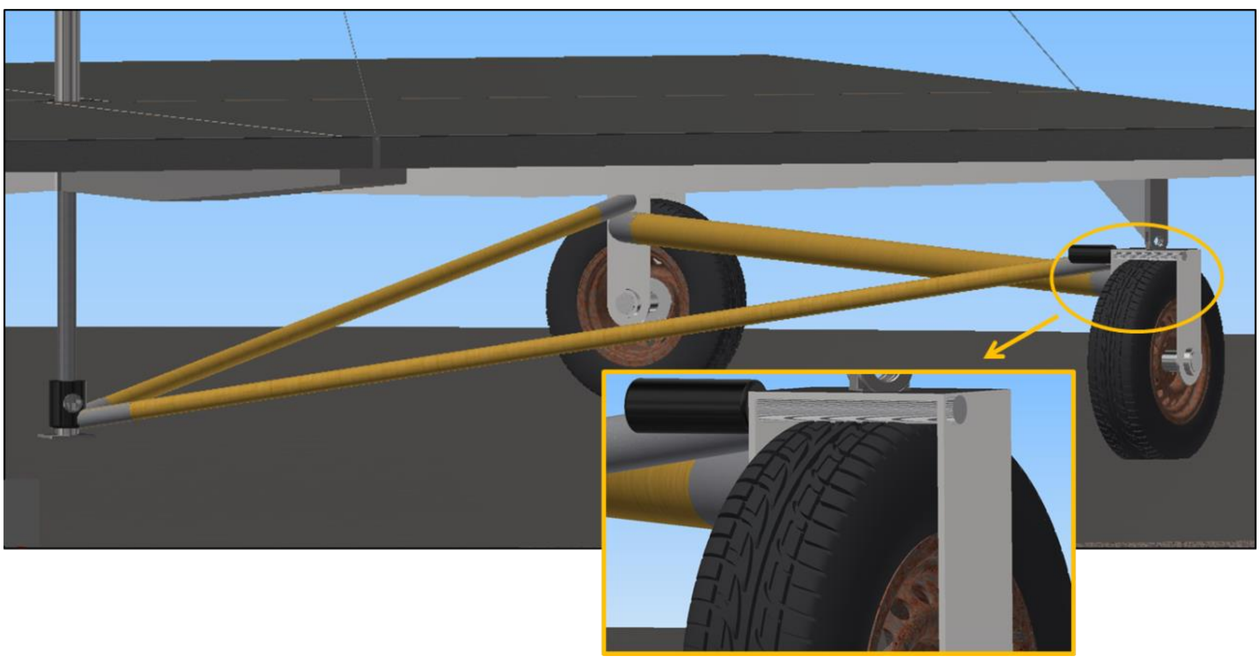

FIGURE 3. Carousel carriage with upcycled car wheels, bamboo tubes, and friction drive

Connecting Tubes

The connecting steel tubes of the carousel are not an important cost factor. However, their cost could also be further reduced by replacing them with bamboo tubes, if available in the region of the power plant. The advantages of bamboo tubes are:

- Low cost
- CO_2-reducing
- High tensile and compressive strength
- Recyclable in the ecological cycle
- High local content if available locally

Bamboo is therefore often called "green steel". The reasons for the very good suitability for the carousel heliostat are

- The heliostat has been designed in such a way that the connecting profiles between the wheels and to the central bearing are almost only loaded by tension and compression and no bending.
- Due to the closed-loop control and the use of gimbal joints for the bearing of the elevation drive, the accuracy requirements for the tubes of the carriage are low, which means that slight deformations occurring over time are permissible.
- Solar sites usually have a rather dry climate, which is favorable for the use of bamboo. The pipes are also protected from direct sunlight by the concentrator and from rain in the safety position (Fig. 4), which means that a sufficiently long life time can be expected.

Elevation Drive

Spindle protection

So far, the spindle of the elevation drive was protected from sand and dust by a rubber bellow. Since it is large in diameter and several meters long, it is relatively expensive. Another disadvantage is its short service life due to its exposure to direct UV radiation. It would have to be replaced several times during the heliostat's service life of 20 - 30 years.

The expensive spindle protection could be avoided by using a scissor mechanism for the elevation drive. Thus, the spindle and its protection can be shorter, of smaller diameter, and is protected from direct sunlight. It could be realized by two small bellows or by a simple encasement in stow position combined with brush rings at the spindle nut. In stow position, the drive is relieved by a support strut which also prevents the heliostat from lifting by strong wind. However, for small elevation angles during operation, the leverage is unfavorable and leads to high loading of the spindle drive (Fig. 4).

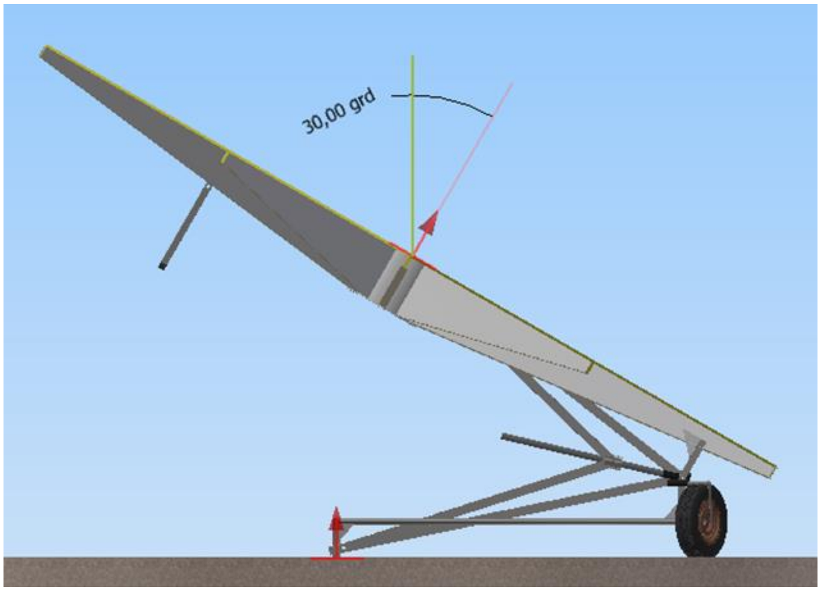

FIGURE 4. Scissor mechanism as elevation drive at 30° elevation angle

For this reason, it is probably cheaper to retain the previous spindle arrangement and replace the bellow by a guyed sheet metal tube (Fig. 5). A disadvantage is that the sheet metal tube does not fold up like the bellow when the mirror surface is raised. On the other hand, the diameter is much smaller, so probably it will not increase the overall shading of the mirror surface.

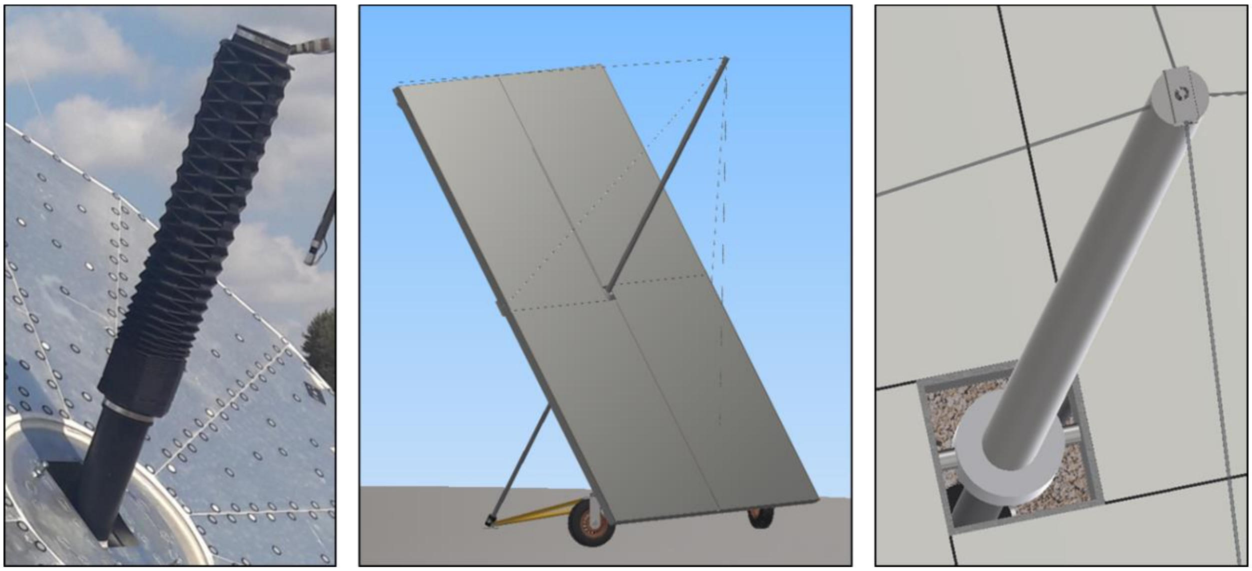

FIGURE 5. Spindle protection with previous rubber bellow and with sheet metal tube suspended by cables

COST AND LOCAL CONTENT ESTIMATIONS

With these innovations, the cost of the single heliostat components can be significantly reduced. Furthermore, their local content is increased because expensive imported products are avoided. For conventional heliostats, the possible local share is in the range of only 40 % while with the new heliostat about 60 % is reached. For low cost countries this leads to an additional cost reduction. All in all a total cost of 71 \$/m² is estimated for a heliostat of 50 m² and assuming high volume production of the single parts and for sites that can be easily leveled (Table 1).

TABLE 1. Innovations in details and estimated cost and local content for 10'000 heliostats of 50 m²

Component	**Innovation**	**Cost (\$/m²)**	**Cost Share**	**Local Content**
Concentrator	Sandwich-cantilever panel	28	40 %	30 %
Azimuth drive	Upcycled car wheels, friction drive, bamboo tubes	7	10 %	80 %
Elevation drive	Guyed sheet metal tube as spindle protection	7	10 %	70 %
Foundation	Stabilized soil for runways, ground anchor	4.5	6 %	90 %
Control and energy supply	Camera based closed loop control	11.5	16 %	70 %
Fabrication/installation/profit		13	18 %	80 %
Total		**71 \$/m²**		**60 %**

HELIOMAROC PROJECT

The HelioMaroc project of Masen and DLR has the aim to increase the local added value of heliostat production and demonstrate the capabilities of participating companies. To achieve this, DLR designed a 9 m² carousel heliostat focused on cost reduction and suitability for local manufacturing. Masen provided the infrastructure and is coordinating two Moroccan industrial consortia in order to build each a prototype (Fig. 6). The required machinery and capacities to manufacture and assembly the parts are available at the selected Moroccan companies. The details regarding the local content rate of the built prototype are shown in Table 2.

TABLE 2. Prototype local content rate

Part	Cost Share (%)	Local Content
Production and mounting	49 %	100 %
Structural components	8 %	70 %
Mirrors	5 %	0 %
Spindle drive	30 %	0 %
Wheels and stepper motor	8 %	0 %
Total	100 %	**55 %**

The HelioMaroc heliostat does not include the newest innovations presented in this paper. However, some important conclusions for future developments can be drawn:

1. Future designs need to leverage existing volume industries in the target country to achieve high local sourcing such as automotive and aerospace in the case of Morocco.
2. This calls for a change of the top-down design approach that was adopted and replaced by a top and bottom convergent design whereas locally mass manufactured parts are considered instead using custom or imported parts.
3. By adopting this method, further cost reductions, a higher local integration, and innovation can be achieved
4. The previous design still called for many parts to be imported which might become a major barrier for mass production and strict working plans as the covid pandemic showed.
5. A tighter control and assembly coordination is crucial for project success, especially if the companies assembling the prototypes have little or no experience with this type of device.

FIGURE 6. Carousel heliostat prototypes of the HelioMaroc project [Jet Energy (left), Aviarail (right)]

SUMMARY AND OUTLOOK

With all the presented innovations in detail, it seems to be well possible to achieve the challenging cost targets that were claimed nine years ago for this year, 2020. Furthermore, a high local content is possible. A precondition for it is the leverage of high volume local industry. Another advantage is the low CO_2-footprint which is achievable by using thin glass mirrors, cardboard honeycomb sandwich core, upcycled wheels, soil stabilization and a ground anchor instead of a heavy foundation, and bamboo tubes.

As next step, some of the innovations are to be realized by a 20 m² heliostat prototype which will be built in spring next year within the SAHEL project.

Of course, what counts is not only the heliostat field but the complete solar tower power plant. Therefore, it is desirable to realize a demonstration plant with similar cost reductions and extraordinary high local content of all components. By this, it could be shown that CSP can provide what is needed so much today: Cost-efficient sustainable and dispatchable energy and high local employment at once.

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