# Competitiveness Perspectives for Vertically Integrated Local PV Manufacturing Until 2025

Philippe Macé, Elina Bosch, Monica Aleman, Gaëtan Masson, Adrien Van Rechem, Damien Gautier
Becquerel Institute, Rue Royale 146, 1000 Brussels (Belgium), p.mace@becquerelinstitute.org

ABSTRACT: The pandemic, combined with additional conjunctural events, led to logistics prices hike as well as increases of raw materials prices. As many other industries, the solar PV sector was impacted, with substantial inflation of PV module prices, which approached the 0,30 US$/Wp. But such turmoil across the supply chain can also create opportunities, e.g. by enabling the competitiveness of local manufacturing in comparison with centralized, large scale manufacturing bases located in Asia. To assess these opportunities, this paper provides estimations of the factory gate cost of manufacturing PV modules using mono c-Si p-type PERC cells, in 2022 and 2025, through vertically integrated factories located in France, Morocco and South Africa of 1GW of production capacity

Results show that it remains challenging to be cost competitive with China-based vertically integrated manufacturing. The gap remains higher than 20%, even in the best-case situation, with 0,37 US$/Wp in France, 0,36 US$/Wp in South Africa and 0,34 US$/Wp in Morocco achievable in 2022. The most influential factors are economies of scale, polysilicon price, cell efficiency or the cost of electricity. Competitiveness can be reached in the medium-term, only by focusing on these factors simultaneously, and with the support of public authorities, direct and indirect.

Keywords: Manufacturing, Techno-economic assessment, Factory, Cost competitiveness

## 1 CONTEXT

The pandemic, combined with additional conjunctural events, led to logistics prices hike as well as increases of raw materials prices. As many other industries, the solar PV sector was impacted, with substantial inflation of PV module prices, which approached the 0,30 US$/Wp while they stood once below 0,20 US$/Wp.

These price shocks can have severe negative effects, for instance for PV project developers, and endanger PV market development. It is therefore of primary importance for many stakeholders in the sector to be able to anticipate, at least partially, the likely evolution of PV module prices, in order to adapt their risk management strategy accordingly. At the same time, such turmoil across the supply chain can also create opportunities, for example by enabling the competitiveness of local manufacturing in comparison with centralized, large scale manufacturing bases located in Asia.

To assess these opportunities, this paper provides estimations of the cost of manufacturing PV modules (factory gate cost) using mono c-Si p-type PERC cells, in 2022 and 2025, through vertically integrated factories located outside of Asia, namely France, Morocco and South Africa. This paper differs from previous research by focusing on original locations, in Europe, but also in other regions which no or limited history as solar PV manufacturing hubs.

## 2 AIM AND APPROACH

### 2.1 Processes' simulation

In order to estimate the cost competitiveness of local manufacturing of solar PV modules with a vertically integrated factory, i.e. starting from ingots up to modules, a multi-step approach has been followed, as described on Figure 1. First, a "bottom-up" simulation model is built, which is a detailed modelling of manufacturing processes along the value chain. This step follows a deterministic approach, with assumptions on various key parameters, for instance uptime, efficiency or energy consumption of the production equipment as well as labour intensity.

### 2.2 Technical assumptions

As the developed techno-economic model follows a deterministic approach, parameters and assumptions are manually defined for the various time-horizons, based on a thorough desk research and interviews with researchers as well as production equipment suppliers or manufacturers, allowing to estimate what is currently achievable in the industry and how it should most likely evolve in the short term.

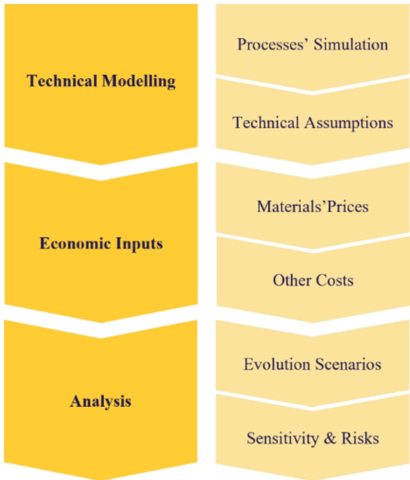


**Figure 1:** Methodolological approach scheme

The technical assumptions feeding the model concern, among others, the following points:

- Ingots & wafers:
  - Consumption of dopants
  - Consumption of polysilicon
  - Lifetime of diamond wires
- Cells:
  - Consumption of silver paste
  - Consumption of aluminum paste
- Modules:
  - Consumption of ribbon
  - Lifetime of laminators' joints

### 2.3 Materials' prices

In addition to this technical modelling of PV module manufacturing, research on input materials' and consumables' prices has been conducted. This allows to evaluate their impact on module prices.

Among these prices used as inputs to the techno-economic model are the following key materials:

- Ingots & wafers:
  - Polysilicon
  - Diamond wire
- Cells:
  - Gazes & chemicals
  - Silver paste
- Modules:
  - Module BOM components (glass, …)
  - Laminators' joints

### 2.4 Other costs

Then, as part of the definition of economic inputs' value required to feed the techno-economic model, some cost constraints had to be defined. These mostly relate to CAPEX, although it also concerns some OPEX. The same methodology as for the prices of materials was used (desk research and interviews). These costs mainly are:

- Ingots to modules:
  - Equipment cost
  - Building & facility cost
  - Financing cost (debt & equity)
  - Labour cost
  - Utility cost
- Modules:
  - Packaging cost

### 2.5 Evolution scenarios

As part of the analysis of the results of the techno-economic modelling, it is important to be able to compare different years for the start of the production, or different situations. For this purpose, various evolution scenarios are defined, considering possible improvements such as:

- Economies of scale
- Increasing efficiencies
- Process optimization
- Prices' variations
- Consumption of input materials and consumables
- Equipment cost
- Labour cost

Note that in our case, the main parameters evolving between a manufacturing plant starting today and 2025 are the polysilicon cost, the cell efficiency, the wafer thickness, the silver consumption, the labour cost as well as the building and facility cost. Due to a too high uncertainty of the future cost of equipment or on the prices of input materials, they have been maintained constant in the analysis.

### 2.6 Sensitivity & risks

The last step is dedicated to a sensitivity and uncertainty analysis, allowing to identify main influencing factors as well as possible deviations of results, and associated risks. Note that all aforementioned parameters can be tested, although only most meaningful ones are.

### 2.7 Regions analyzed

This paper focuses on the potential competitiveness of local manufacturing outside of the large-scale, centralized manufacturing bases located in Asia. The three countries targeted here are France, Morocco and South Africa.

## 3 MAIN ASSUMPTIONS

A vertically integrated factory with 4 main stages has been simulated: ingots' pulling (mono c-Si p-type), wafers' slicing (M10), cells' manufacturing (PERC) and modules' assembling (144 half-cells glass-backsheet). A production capacity of 1GW at each step is considered.

The computed cost is the factory gate cost, i.e. without transportation cost.

Two different years for the start of the production (2022 & 2025) have been tested. The evolving factors between these two years are the following:

- Labour, facility and building costs, whose evolutions are due to the inflation considered for these three countries.
- The polysilicon price, which is expected to significantly decrease in the next few years. This decrease is foreseen as many production capacities' expansions have been announced.
- Technical assumptions, like cell efficiency, CTM ratio, wafer thickness or silver consumption. These are made according to the latest ITRPV report [1].

The values of these evolving factors as well as other assumptions are presented in Table I on the next page. The value of annual inflation is from the year 2021i [2]. It is considered that this value will remain study until 2025. Also, this inflation has not been considered for cost items such as input materials (glass, frames, …) or energy, whose prices are currently very high and are not expected to remain so by 2025. We thus anticipate a stagnation of their nominal value but a decrease of their real value.

Finally, values of other assumptions such as the price of consumables, labour intensity or the performances of production lines (uptime, rate of defects) are not presented here. These are indeed sensitive data and displaying them all would make the present paper too long.

**Table I** Main assumptions used in the simulations for 2022 and 2025

| 2022 / 2025 | France | Morocco | South Africa |
|---|---|---|---|
| **Cost of capital** | | | |
| Cost of debt | 6% | 7% | 8% |
| Cost of equity | 10% | 12% | 12% |
| Debt to equity ratio | 70 / 30 | 70 / 30 | 70 / 30 |
| **Labour (k$ per year)** | | | |
| Operator | 35 / 37 | 6 / 7 | 25 / 29 |
| Technician | 46 / 49 | 10 / 11 | 41 / 47 |
| Engineer | 73 / 78 | 14 / 16 | 75 / 86 |
| **Energy** | | | |
| Electricity cost (US$/kWh) | 0.06 | 0.101 | 0.065 |
| **Inflation** | | | |
| Annual average inflation | 2% | 1.4% | 4.6% |
| **Market** | | | |
| Polysilicon price (US$/kg) | 40 / 10 | 40 / 10 | 40 / 10 |
| **Equipment** | | | |
| Ingots & Wafers (MUS$/GW) | | 80.2 | |
| Cells (MUS$/GW) | | 35.8 | |
| Modules (MUS$/GW) | | 18 | |
| **Other cost** | | | |
| Facility (MUS$) | 19.5 / 20.7 | 13.6 / 14.2 | 17.5 / 20.1 |
| Building (MUS$) | 11.7 / 12.4 | 8.2 / 8.5 | 10.5 / 12.0 |
| **Technical assumptions** | | | |
| Cell efficiency (M10) | | 23% / 23.8% | |
| CTM ratio | | 1.009 / 1.0105 | |
| Wafer thickness (µm) | | 155 / 145 | |
| Silver consumption (mg/cell) | | 94 / 85 | |

## 4 RESULTS

The following bar charts represent the factory gate cost of solar PV modules manufactured in a vertically integrated plant that would be launched in 2022 or 2025, in each country studied.

These costs are divided into the four main stages of the production line: ingots' pulling (mono c-Si p-type), wafers' slicing (M10), cells' manufacturing (PERC) and modules' assembling (144 half-cells glass-backsheet). The production capacity at each stage of the production line is estimated at 1GW. The result is given in US dollar per Wp for each stage.

### 4.1 Manufacturing activity starting in 2022

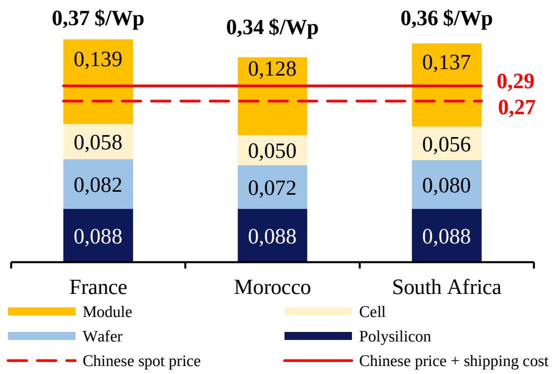


**Figure 2:** Factory gate cost of solar PV modules (launch in 2022)

The results for the tested countries range between 0,34 and 0,37 US$/Wp in 2022, as shown on Figure 2 above. This is >20% more than the average spot prices for the same types of modules, produced in China, around 0,27 $/Wp currently [3]. Even adding the costs of shipping Chinese modules (0,02-0,03 US$/Wp) to Europe or Africa, the gap remains substantial. Especially as these costs have been decreasing for a few months [4].

This difference can be explained by various factors. First, the very small scale of the manufacturing activity simulated here, compared to the scale of factories in China, where 5 GW is a minimum and 10 to 20 GW the norm, especially at upstream steps.

Then, one can also mention further key advantages, such as grants, tax exemptions, access to cheap financing, public support for the construction of buildings, facilities, infrastructures or networks (electricity, gas, water), public contribution to workforce's training or transportation, special conditions in terms of labour taxation, …

### 4.2 Manufacturing activity starting in 2025

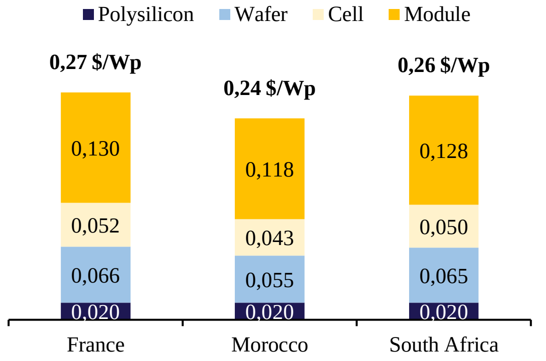


**Figure 3:** Cost of manufacturing PV modules in 2025

Then, in the case where the manufacturing activity starts in 2025, the situation is expected to improve. A decrease of 0,10 US/Wp of the total factory gate cost of modules has been estimated, as shown above on Figure 3.

But this decrease is mainly achieved thanks to external factors, as further detailed on the graph below.

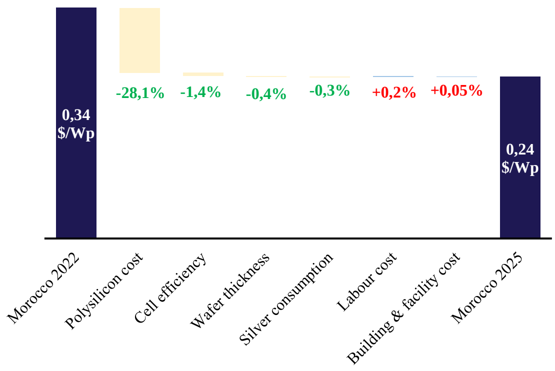


**Figure 4:** Main influencing factors of the decrease between 2022 and 2025

This graph shows the sources of the cost differences between starting a manufacturing activity in Morocco in 2022 or in 2025. The main decrease in module manufacturing cost by 2025 should come from the expected decrease in the price of polysilicon. Improvements in cell efficiency, wafer thickness or silver consumption will also contribute to the cost reduction, but to a much lesser extent. On the other hand, the increase in labour and construction costs, assumed to be caused by inflation, is expected to have a limited negative effect. Note that to simplify calculations, this inflation has not been considered for cost items such as input materials (glass, frames, …) or energy, whose prices are currently very high and are not expected to remain so by 2025.

## 5 ANALYSIS OF INFLUENCING FACTORS

In this section, the main influencing factors on the cost of manufacturing c-Si solar PV modules will be studied and their impact quantified. First, the effect of economies of scale, with a shift towards a factory with 5GW of production capacity instead of 1GW, as in our base case. Here, we focus on the situation of Morocco.

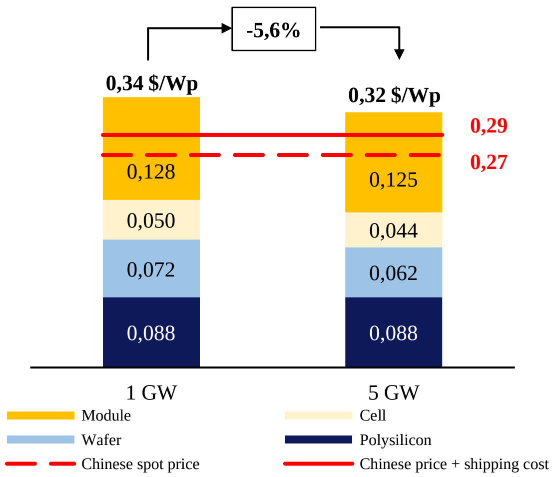


**Figure 5:** Effect of economies of scale on the factory gate cost of solar PV modules made in Morocco, in 2022

As shown on the graph above, the increase in scale could permit to decrease the factory gate cost of locally manufactured solar PV module by 0,02 US$/Wp, or approximately 6%. While limited in scale, this is still a significant improvement. It is also worth highlighting that this scale effect is particularly important at upstream steps, i.e. ingots and wafers as well as cells manufacturing. Focusing on the assembling of modules, the effect is negligible.

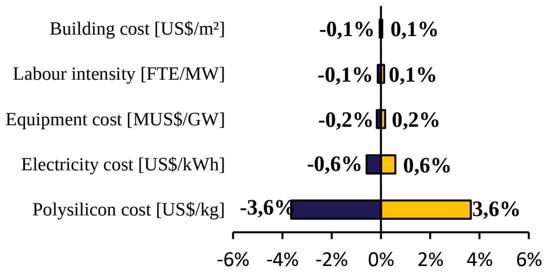


**Figure 6:** Variation of PV modules' factory gate cost in case of 10% variation of input parameters' values

Looking at other parameters' influence, the conclusions from Figure 4 focusing on the evolution between 2022 and 2025 are confirmed. Indeed, as shown by the graph above with results of the sensitivity analysis, polysilicon pricing is by far the most influential factor of the manufacturing cost of PV modules.

Electricity cost being a far second, with only 0,6% module cost variation when electricity cost varies by 10%. As shown by the Figure 4, a parameter like cell efficiency is more than twice as impactful.

While not studied in this paper, other consumables' price such as silver paste also have a significant influence on the module price. Although, it is not as high as polysilicon's

Then, CAPEX (e.g., equipment or building cost) and OPEX (e.g., labour intensity and cost) elements are much less influential.

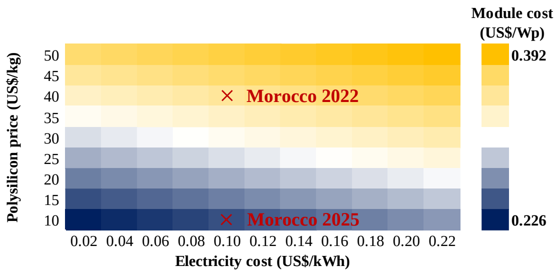


**Figure 7:** Sensitivity analysis based on the prices of poly-Si & electricity

Focusing specifically on these two influential cost factors, i.e. electricity cost as well as polysilicon pricing, it appears that by 2022 already, in a very favorable scenario (poly-Si at 10 US$/kg and electricity at 0,04 US$/kWh), the factory gate cost of PV modules could approach 0,20 US$/Wp in Morocco.

Although, such decrease of polysilicon is an external factor and would benefit all actors in the sector, including Chinese ones. Thus, the gap between Chinese-made modules and local ones would persist.

## 6 CONCLUSIONS

In this paper, we demonstrated that it remains challenging to be cost competitive with China-based vertically integrated manufacturing in different regions of the world. Indeed, the gap in terms of factory gate cost remains higher than 20%, even in the best-case situation.

Another conclusion is that vertical integration only makes sense if sufficient scale can be reached at all steps, otherwise specialization is better. The main steps where scale is crucial are upstream, in our case from ingots to cells, as shown by the results on Figure 5.

Although challenging, competitiveness can be reached in the medium-term, by playing on different factors simultaneously. First, by leveraging the currently high cost of shipping (0,02-0,03 $/Wp), which can advantage local manufacturing. Nonetheless, these cast are decreasing. Hence, this card should not be overplayed.

Then, our calculations showed that even the most influential factor, i.e. polysilicon price, only influences the factory cost of modules by ~3,5% when changing by 10%. Thus, even if no factor will be single-handedly impactful enough to reach the competitiveness of Chinese manufacturing hubs, a combination of the following factors could allow to approach it.

- Technical innovations (cell efficiency, wafer thickness, material intensity, module-level improvements, …).
- Reaching sufficient scale, which is crucial to enable cost savings, especially at upstream steps. 5GW appears as a minimum, while 10GW or even 20GW are the optimum (1GW only was considered here).
- Public authorities' support through:
    - Access to low-cost loans to reduce the cost of capital
    - Direct (e.g., grants) or indirect reductions of CAPEX
    - Guaranteed off-taking to reduce risk, thereby increasing the confidence of potential investors and decreasing the average cost of capital. This can be achieved via mechanisms such as public procurement of locally manufactured PV modules, or tenders where feed-in tariffs are conditioned by the development of local factories.

Finally, it is crucial to keep in mind that local manufacturing is much more than just an economic question. It is a matter of energy independency, local job creations, social acceptance of renewables, supply risk as well as geopolitical risk management.

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