



# **THE WAY TO BEST LCOE**

**Photovoltaic System Study:  
CAPEX and LCOE Assessment  
White Paper**

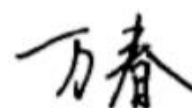
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## Foreword

*Firstly, I would like to thank Trina Solar inviting me to write a foreword for this White Paper. DNV has a long-term cooperation with Trina Solar in many areas. With the rich and extensive industrial experience, we have been requested by Trina Solar to conduct an LCOE analysis for comparing three different types of modules for an assumed PV plant located in Spain. The results show that larger module will have more save in CAPEX and LCOE side, and the larger module would be the industry trend for next decades.*

*Finally, I would like to congratulate Trina Solar on the official released White Paper, which I think will give some ideas or guidance to help EPCs and customers to make better decisions for investing in a PV project.*



*Wan Chun  
Head of Renewable  
DNV (China) Company Limited*

*It was my honour for being invited to write a preface for the official released Trina Solar white paper. With the purpose to have an idea of how the CAPEX and LCOE vary with different solar modules under the same project conditions, Trina Solar has requested us to perform an LCOE assessment for 182mm-540Wp and 210mm-660Wp modules in Australia and UAE. UL noted that the CAPEX and LCOE decreased by 1.5-1.7% and 1.2-1.3%, respectively, for the 660Wp system in comparison to the 540Wp system.*

*It has been a pleasure working with top PV module suppliers like Trina Solar. Apart from the LCOE study, we have also worked with Trina Solar in many other areas like certifications and testing. I believe that the Trina Solar white paper may offer some reference for selecting modules and design of the solar power plants.*



**Daniel Liang, PhD**  
**Head of ESS Advisory – APAC**  
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# 1 Introduction

Facing climate change, the need for the world to transition to green and low-carbon development is becoming more and more crucial and urgent. Recently, many countries have set the target of climate neutrality in law. In 2020, China has officially committed to peaking emissions by 2030 and achieving carbon neutrality by 2060. It is believed that wind and solar PV will continue to play important roles in accelerating sustainability and global transition to clean energy.

As the solar PV technology advances, various wafer sizes have been introduced into the industry, leading to a diverse of modules with different wafer sizes available on the market. The abundant choices make it difficult to select the best-fit solar PV module for a specific project. Aiming at figuring out the cost differences at system level for different modules, the world-leading third-party institutes have conducted a series of case studies across the world. These studies investigated solar PV systems with various installation methods (1P tracker, 2P tracker, fixed-tilt) and inverters (string inverter, central inverter) in different countries worldwide, including Germany, Spain, US, Brazil, Australia, and UAE.

The main purpose of this white paper is to summarize and compare the assessment results for the studied solar PV plants in different application scenarios. Supported by large amount of data, this white paper will show the results mainly with two indicators, the Capital Expenditures (CAPEX) and Levelized Cost of Electricity (LCOE), to provide references and help to design an optimized PV system for EPCs and customers, especially downstream power plant investors. At the same time, these findings may provide a clear direction and technical path for the continuous improvement of photovoltaic modules in the future, which could further reduce photovoltaic system costs to accelerate a wider application of photovoltaic power.

This white paper is fully based on the research results of the third-party research institutes and developers, including Fraunhofer ISE, Enertis Applus+, UL, DNV, and BLACK & VEATCH. The paper directly quoted the assumptions, calculation methods, calculation results and research conclusions of the original reports without any amending. Here, we would like to thank the following organizations for carrying out the original studies:

Fraunhofer Institute for Solar Energy Systems ISE, Enertis Applus+, UL, DNV, and BLACK & VEATCH.



## About Trina Solar

Since 1997, Trina Solar has been driven by innovation, reliability, quality and customer value. Since the release of the first advanced Vertex 210mm modules in February 2020, the product line has been stacked with different products including Vertex S 400W module, and the Vertex series of 500W, 550W and 600W modules and beyond, which fit well with the applications of residential, commercial and large scale power plants, as well as multiple scenarios of agriculture and fisheries. As planned by Trina Solar, the capacity of PV modules will be no less than 50GW by the end of 2021, and it will continue to strengthen the capacity of advanced modules with large-size cells in the future.

In the era of grid parity of solar energy, the Vertex series module have a prominent edge in LCOE that maximize the value for customers. With the close partnership in the 600W+ Photovoltaic Open Innovation Ecological Alliance members, along with the design mindset of low voltage, high string power, modules, trackers, inverters as well as solutions are all in place. This is a critical step for the photovoltaic industry to reach the best LCOE. Trina sets a new cost-saving standard, ultimately ensure the project's earnings and maximize customer value, making PV solar energy more cost competitive.

## 2 PV System Values (CAPEX & LCOE)

### 2.1 Capital expenditures (CAPEX)

One of the most critical ways of assessing a solar PV plant is to accurately estimate the capital expenditures (CAPEX). The value of CAPEX is fundamentally composed of two following cost groups:

- The main equipment (PV modules, inverters and racking systems);
- The other materials (cabling, combiner boxes, etc.), installation works (civil, electrical, mechanical) and management costs.

The differences in the project's initial investment cost are primarily due to varying Balance of System BOS material, BOS installation, and indirect construction costs. These costs are impacted by the overall module wattage, the amount of modules and the number of strings required to meet the constant capacity assumptions of the hypothetical projects. A project utilizing a module with a lower wattage and a higher voltage will require more modules and strings therefore more BOS material, installation and indirect construction costs which impact the amount of land use, site clearing and grading, racking quantity, and cabling required.

### 2.2 Levelized cost of electricity (LCOE)

The LCOE is a measurement used to assess the energy production, comparing the performance of PV system plant with different cost and power capacity. The calculation of the lifecycle electricity generation, the operations and maintenance expenditures (OPEX) and residual value of equipment are conducted by using their net present value (NPV). The lower the value of LCOE of a PV plant, the cheaper of the power generation from solar energy, the greater the competitiveness in the power market.

The following formula is widely accepted and used to calculate LCOE by organizations as NREL and IRENA:

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

where:

$I_t$ : investment expenditures in the year t

$M_t$ : operations and maintenance expenditures

$F_t$ : fuel expenditures in the year t

$E_t$ : electricity generation in the year t

$r$ : discount rate

$n$ : economic life of the system

According to the formula, the LCOE is proportional to the total cost throughout the project lifetime, e.g., the CAPEX and the OPEX, and it is inversely proportional to the total electricity generation throughout the project lifetime. If the projects are only different in terms of the module used (the same project location, lifespan etc.), the main affecting factors of the LCOE is the CAPEX and the total power generation during service time. According to the assessment from the institutes, the total power generation of a PV plant is similar when using different modules (P-type), while only the CAPEX has a significant influence on the LCOE. In other words, the lower CAPEX means the lower LCOE when there is only a small gap between the electricity generation.

Reviewing the LCOE studies conducted by the institutes, the unique characteristic of low-voltage design of 210mm modules gives high string power, leading to a lower CAPEX, and therefore reduces the LCOE. The details of string power are further introduced in Chapter 2.3.

## 2.3 Low-voltage and high string power design

The module string is a string that connects a certain number of modules in series. Typically, the power of a single module is about 400W to 600W+ and the voltage is 40V to 50V, which are below the starting voltage of the inverter. Therefore, a certain number of modules must be connected in series to form a string to reach the starting voltage of the inverter and therefore generate AC power.

String power is equal to the number of modules that can be connected to the string multiplied by the power of a single module:  $P_{\text{string}} = N \times P_{\text{module}}$ . The number of modules that can be connected in a string, according to the PV system design specifications, needs to satisfy the following equation:

$$N \leq \frac{1500V}{V_{OC} \times [1 + (t - 25) \times K_v]}$$

where  $K_v$  is the open-circuit voltage temperature coefficient of the PV module, and  $t$  is the ultimate low temperature of the PV module under the operating conditions.

To increase the number of modules that can be connected in a string,  $V_{OC}$  needs to be reduced. the smaller the value of  $V_{OC}$ , the greater the number of modules that can be connected at a given system voltage. Moreover, with the increase in module current  $I_{SC}$ , it is possible to simultaneously increase both the module power and the string power. For example, compared to the conventional 182-540W module, the module power and string power of the 210-660W module with low-voltage design is significantly boosted by 22% and 36%, respectively, under the system voltage of 1500V. As a consequence, it saves the material and labor costs of DC terminals, and thus reduce the system's CAPEX and LCOE.

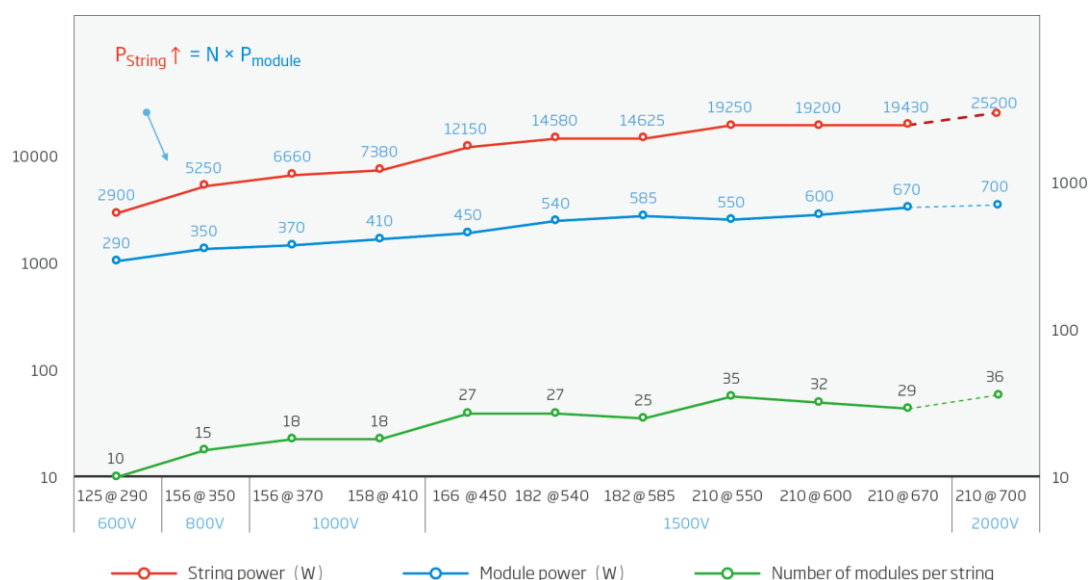


Figure 1 The past development and future estimation of module power and string power.

The development trend of module power and string power is shown in Figure 1, the power of the PV modules has been increased from just about 290W to 670W in the last 10 years. Furthermore, the PV system voltage has also increased from 600V to the current value of 1500V. The number of modules that can be connected in the string has been increased from 10 to more than 30 pieces. From a system point of view, the increase in string power (from 2900W to the current level of 19,430W) is attributed by the increase in system voltage and module power. This is ultimately reflected in the reduction of CAPEX, including mounting system, piles, DC cables, labor, and other costs, which is consistent with both the industry development trend and the end customers' target of value maximization.

## 2.4 Other impact factors in LCOE

In this section, other aspects of solar PV modules, like module reliability and power degradation are addressed and discussed in details. The module's reliability is one of the important factors to be considered in its service time. Trina Solar has tested the PV modules in a harsher environment than the standard IEC test conditions. The five harsher tests are the non-uniform snow load test, static loading under -40°C, 35mm hail impact test, enhanced dynamic load test, and wind tunnel test. In the static load tests, the results show that 210mm Vertex modules passed the standard IEC tests, showing that as a high-power module, the Vertex modules still maintained the same level of mechanical performance as the conventional modules. The power degradation of modules is a factor that can affect the power generation in its whole service life. The 210mm module has lower or equal power attenuation than the 182mm or 166mm modules, which means that the 210mm module generate equal or even more electricity during their life cycle based on the same project capacity, resulting in a lower LCOE. For the 210mm module represented by Trina Vertex module, the annual linear degradation of monofacial module is 0.55% and 0.45% for the bifacial modules.

### 3 CAPEX and LCOE Study Results

The five world-leading institutes have carried out hypothetical studies to investigate the CAPEX and LCOE of PV systems with different module alternatives. The studies were defined in various application scenarios (fixed-tilt, 1P tracker, 2P tracker) and in different locations worldwide, including Spain, Germany, Australia, UAE, Brazil, and USA.

Despite the differences in the application scenarios, all the hypothetical studies reflected the fact that Trina Solar 600W+ products could reduce more CAPEX and LCOE than the 182mm and 166mm modules. The Figure 2 shows the overall results of LCOE comparison between 210-665/660W and 182-540/535W modules. According to the results derived by different institutes, in comparison with 182-540/535W modules, the 210-665/660W modules can save LCOE about 4.09% for fixed-tilt system and 1.19%-2.55% for tracking system. Following this round of study, more worldwide investigations, such as in China, Japan, are going to be launched to demonstrate the advantage of 210mm modules, whose assessment results will be updated to our database dynamically.

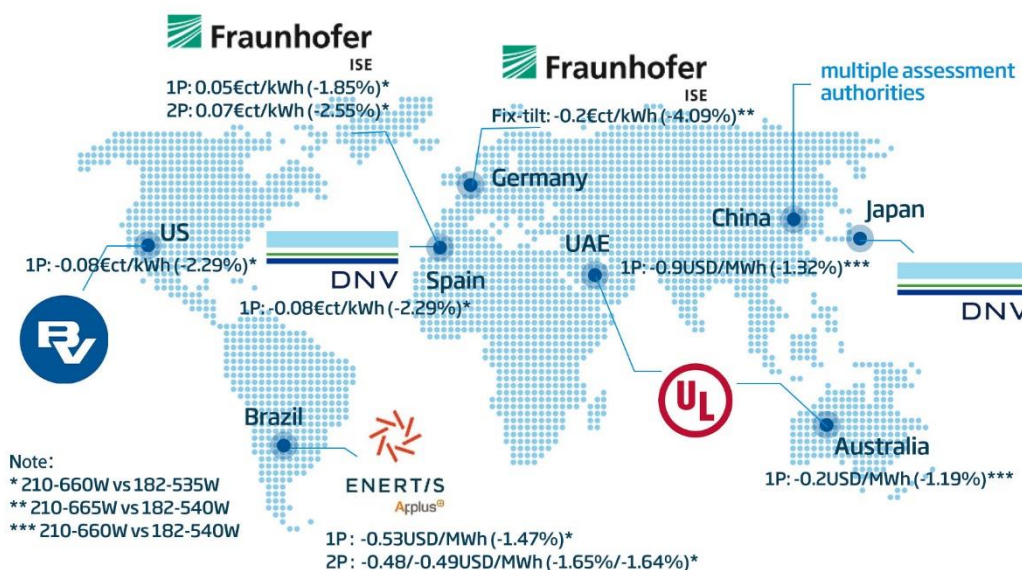


Figure 2 LCOE comparison between the 210-665/660W module and the 182-540/535W module

#### 3.1 Study on fixed-tilt and tracking PV systems in EU by Fraunhofer ISE

Founded in 1981, Fraunhofer ISE is the largest solar research institute in Europe. Based in Freiburg, Germany, it is a constituent entity of Fraunhofer-Gesellschaft, the world's leading applied research organization. Headquartered in Munich, Germany, Fraunhofer has more than 20,000 qualified scientists and engineers in 74 institutes and research institutions worldwide.

The study deals with three simulated PV systems with a capacity of rough 10MW and 50MW located in Germany and Spain, respectively. The details of each system is shown in Table 1. For the site in Germany, the average annual global horizontal irradiation on a horizontal plane is 1087 kWh/m<sup>2</sup>/year. The same value for the site in Spain is 1796 kWh/m<sup>2</sup>/year. In each location, total six different types of modules with three different wafer sizes (166mm, 182mm and 210mm) are applied for the comparative study.

*Table 1 The three plant configurations in the study conducted by Fraunhofer ISE.*

Item	Plant 1	Plant 2	Plant 3
Project capacity(DC)	10 MW	50 MW	50 MW
Mounting	Fixed-tilt 4L	1P tracker	2P tracker
Inverter	String inverter	Central inverter	Central inverter
Module type	Monofacial: 166-455W, 182-540W, 210-550W, 182-590W, 210-605W, 210-665W Bifacial: 166-450W, 182-535W, 210-545W, 182-585W, 210-600W, 210-660W		
Project site	Brandenburg, Germany	Badajoz, Spain	Badajoz, Spain

### 3.1.1 PV system with fixed-tilt in Germany

The system with a capacity of 10MW in Germany is defined as a fixed-tilt ground-mounted system (4L) that uses monofacial modules and string inverter. It is assumed that the site is flat and large enough for the planned plant size. No shading caused by external objects such as buildings or trees are considered in the project.

The study documents the electricity yield to be generated by the PV system. In the preparation of the yield assessments, time series data with 15 min. step for the last ten years (2011-2020) are used according to the state of the science. The irradiation and temperature data used for the project are acquired from Solargis s.r.o., giving a global horizontal irradiation of 1087 kWh/m<sup>2</sup>/year and average ambient temperature of 9.9 °C. The project assumptions are listed in Table 2.

*Table 2 The project assumptions of the fixed-tilt PV system in Germany.*

Project site	Brandenburg, Germany
Annual GHI	1087 kWh/m <sup>2</sup>
Average ambient temperature	9.9 °C
Project size	10 MW
Mounting	Fixed-tilt 4L
Inverter	String inverter

The arrangement of the module and inverter in the analyzed PV system are listed in Table 3. The overall idea of configuring the system is to reach the closest value of DC capacity to 10MW, while the numbers of inverter and transformer are kept the same for all the compared systems.



Table 3 The configurations of the fixed-tilt PV system in Germany

Module Type	166-455W	182-540W	210-550W	182-590W	210-605W	210-665W
Module Power (W)	455	540	550	590	605	665
Module Size (mm)	2102x1040	2256x1133	2384x1096	2411x1134	2172x1303	2384x1303
Inverter	SUN2000-215KTL-H0 / SUN2000-215KTL-H3					
Modules/String	28	28	37	26	34	31
Strings/Inverter	19	16	12	16	12	12
String power (kW)	12.74	15.12	20.35	15.34	20.57	20.62
DC/AC Ratio	1.14	1.13	1.15	1.14	1.15	1.15
Pitch (m)	6.03	6.56	6.35	6.56	7.53	7.53
Tilt angle	20°					
Shading angle	35°					
GCR	65.8%					
DC Capacity (kW)	9,924	9,919	10,012	10,063	10,120	10,143
AC Capacity (kW)	8,815					
Module numbers	21,812	18,368	18,204	17,056	16,728	15,252
Inverter numbers	41					

Table 4 lists the CAPEX and LCOE results of the PV system for the six different modules. It can be said that the total module cost has the highest contribution to the CAPEX. The module supply cost was assumed to be same for all module types, thus the difference in cost occur due to the transportation cost.

Figure 3 shows the percentage reduction in CAPEX and LCOE compared to the 166-455 module. It indicates that overall the 210 modules have a lower CAPEX and LCOE. Compared with 166-455W module, 210 modules reduce both the CAPEX and LCOE by more than 4%, of which 210-665W performs the best, with the highest reduction of 7.42% (3.68 €/ct/W) in CAPEX and 7.68% (0.39 €/ct/kWh) in LCOE. The 210-605W module comes in the second best place, with the ability to reduce the CAPEX by 6.47% (3.21€/ct/W) and LCOE by 6.50% (0.33 €/ct/kWh).

Table 4 The CAPEX and LCOE results of the fixed-tilt PV system in Germany.

Module Type	166-455W	182-540W	210-550W	182-590W	210-605W	210-665W
Unit: €/ct/W						
Module	26.07	25.78	25.72	26.30	25.75	25.43
Inverter	3.11	3.11	3.08	3.07	3.05	3.04
Civil works	2.30	2.25	2.17	2.22	2.19	2.19
Electrical system	4.23	3.78	3.64	3.62	3.45	3.33
Mounting	8.60	7.75	7.59	7.64	6.65	6.64
<b>CAPEX</b>	<b>49.61</b>	<b>47.97</b>	<b>47.51</b>	<b>48.14</b>	<b>46.40</b>	<b>45.93</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-1.64</b>	<b>-2.10</b>	<b>-1.47</b>	<b>-3.21</b>	<b>-3.68</b>

Land	0.171	0.167	0.167	0.164	0.166	0.166
OPEX	0.99	0.96	0.95	0.96	0.93	0.92
Unit: €ct/kWh						
<b>LCOE</b>	<b>5.08</b>	<b>4.89</b>	<b>4.86</b>	<b>4.91</b>	<b>4.75</b>	<b>4.69</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.19</b>	<b>-0.22</b>	<b>-0.17</b>	<b>-0.33</b>	<b>-0.39</b>

\*miscellaneous and soft BOS cost are not shown in the table.

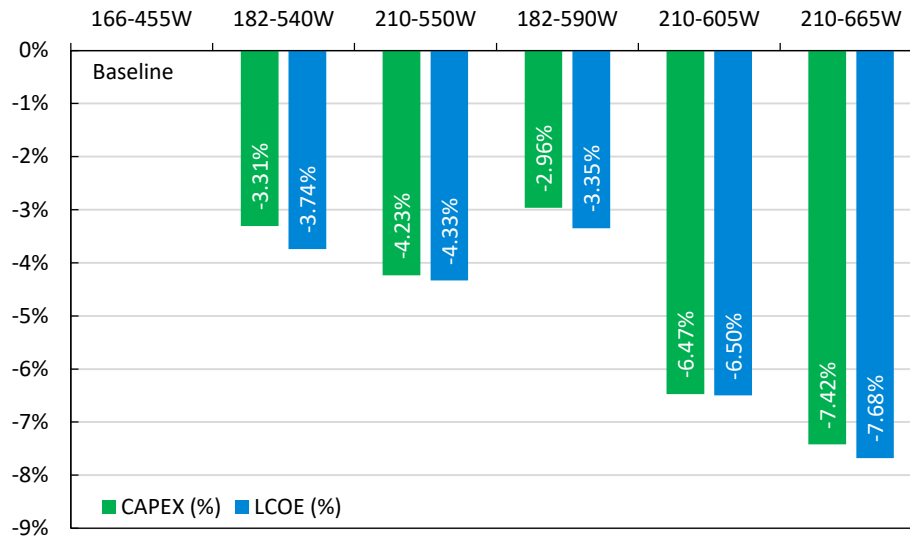


Figure 3 The comparison of CAPEX and LCOE with 166-455W for the fixed-tilt PV system in Germany.

The breakdown of CAPEX in comparison with 166-455W is illustrated in Figure 4. It shows that the savings mainly come from the electrical system and mounting, regardless of the module types. However, the 210-665W module has the highest saving in percentage with more than 21% in electrical system and more than 22% in mounting.

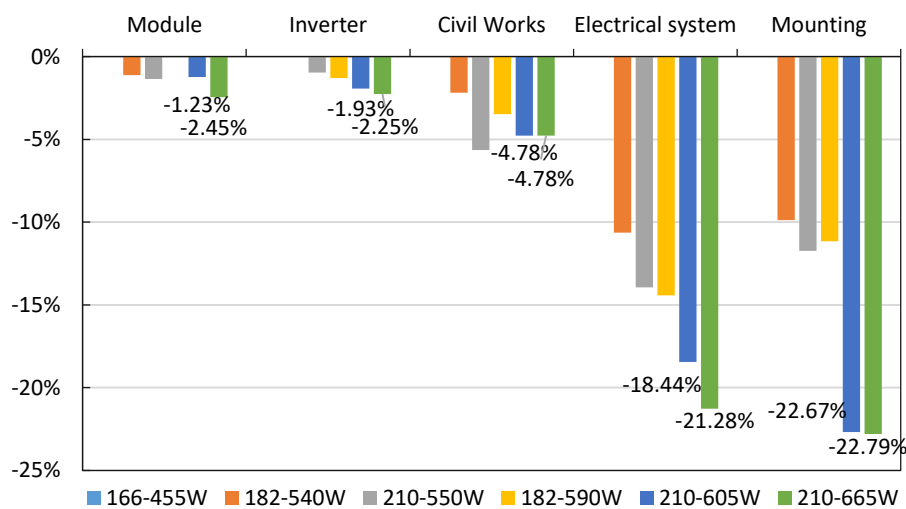


Figure 4 The breakdown of CAPEX in comparison with 166-455W for the fixed-tilt PV system in Germany.

### 3.1.2 PV system with 1P tracker in Spain

One of the systems with a capacity of 50MW in Spain is defined as single-axis tracking with one module row (1P) system. The system uses bifacial modules with central inverters. It is assumed that the site is flat and large enough for the planned plant size. No shading caused by external objects such as buildings or trees are considered in the project. The project assumptions are listed in Table 5.

*Table 5 The project assumptions of the 1P tracking PV system in Spain.*

Project site	Badajoz, Spain
Annual GHI	1796 kWh/m <sup>2</sup>
Average ambient temperature	17.4 °C
DC capacity	50 MW
Mounting	Single-axis 1P tracker
Inverter	Central inverter

The arrangement of the module and inverter in the analyzed PV system are listed in Table 6. The overall idea of configuring the system is to reach the closest value of DC capacity to 50MW, while the numbers of inverter and transformer are kept the same for all comparing systems.

*Table 6 The configurations of the 1P tracking PV system in Spain.*

Module Type	166-450W	182-535W	210-545W	182-585W	210-600W	210-660W
Module Power (W)	450	535	545	585	600	660
Module Size (mm)	2102x1040	2256x1133	2384x1096	2411x1134	2172x1303	2384x1303
Inverter	SG3125HV-20					
Modules/String	28	29	38	26	34	31
Strings/Inverter	330	268	201	273	204	203
String power (W)	12.60	15.52	20.71	15.21	20.40	20.46
DC/AC Ratio	1.16	1.16	1.16	1.16	1.16	1.16
Pitch [m]	5.28	5.64	5.96	6.03	5.43	5.96
Strings/Tracker	4	4	3	4	3	3
Tracker number	990	804	804	819	816	812
GCR	40%					
DC Capacity (kW)	49,896	49,896	49,953	49,828	49,939	49,841
AC Capacity (kW)	43,116					
Module numbers	110,880	93,264	91,656	85,176	83,232	75,516
Inverter numbers	12					

In this study, an average DC wiring section of 6mm<sup>2</sup> was considered for the 210mm cell modules due to their higher currents (while a section of 4mm<sup>2</sup> was used for the rest of the modules).

Table 7 The CAPEX and LCOE results of the 1P tracking PV system in Spain.

Module type	166-450W	182-535W	210-545W	182-585W	210-600W	210-660W
Unit: €/ct/W						
Module	25.87	26.12	26.05	26.64	26.14	25.76
Inverter	3.03	3.03	3.03	3.03	3.03	3.03
Civil works	2.18	2.14	2.13	2.09	2.10	2.11
Electrical system	2.83	2.41	2.25	2.32	2.15	2.09
Tracker & Mounting	12.38	10.75	10.44	10.63	10.79	10.51
<b>CAPEX</b>	<b>51.10</b>	<b>49.26</b>	<b>48.71</b>	<b>49.52</b>	<b>49.02</b>	<b>48.31</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-1.84</b>	<b>-2.39</b>	<b>-1.58</b>	<b>-2.08</b>	<b>-2.79</b>
Land	0.151	0.148	0.147	0.143	0.145	0.145
OPEX	1.02	0.99	0.97	0.99	0.98	0.97
Unit: €/ct/kWh						
<b>LCOE</b>	<b>2.82</b>	<b>2.70</b>	<b>2.67</b>	<b>2.72</b>	<b>2.68</b>	<b>2.65</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.12</b>	<b>-0.15</b>	<b>-0.10</b>	<b>-0.14</b>	<b>-0.17</b>

Table 7 lists the CAPEX and LCOE results of the PV system for the six different modules. Based on the data, the percentage reduction of CAPEX and LCOE is shown in Figure 5. The results are the same as the fixed-tilt PV system in Germany, it indicates that overall the 210 modules have a lower CAPEX and LCOE. Compared with 166-450W module, 210 modules reduce both the CAPEX and LCOE by over 4%, of which 210-660W performs the best, with the highest reduction of 5.46% (2.79 €/ct/W) in CAPEX and 6.03% (0.17 €/ct/kWh) in LCOE. The study results also show that the 210-545W module being the second best for tracker installation with the reduction of 4.68% (2.08 €/ct/W) in CAPEX and 5.32% (0.14 €/ct/kWh) in LCOE.

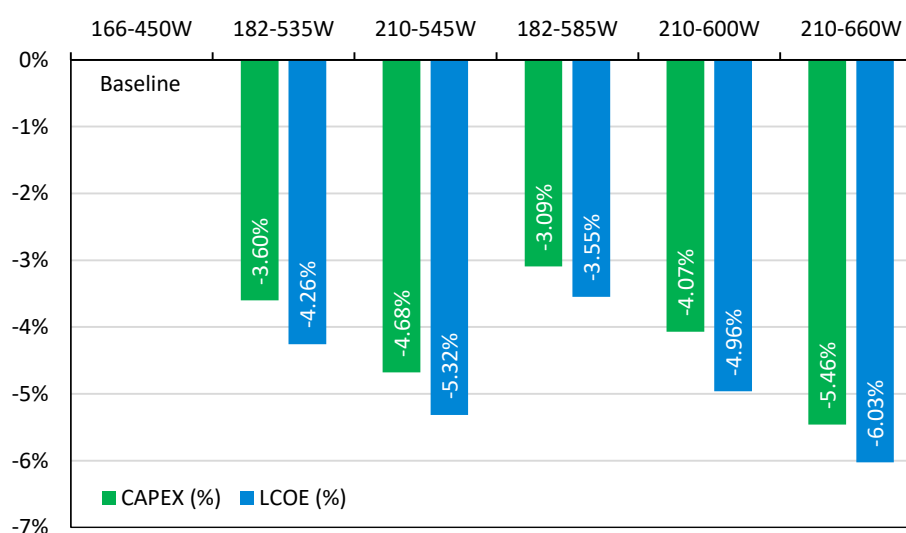


Figure 5 The comparison of CAPEX and LCOE with 166-450W for the 1P tracking PV system in Spain.

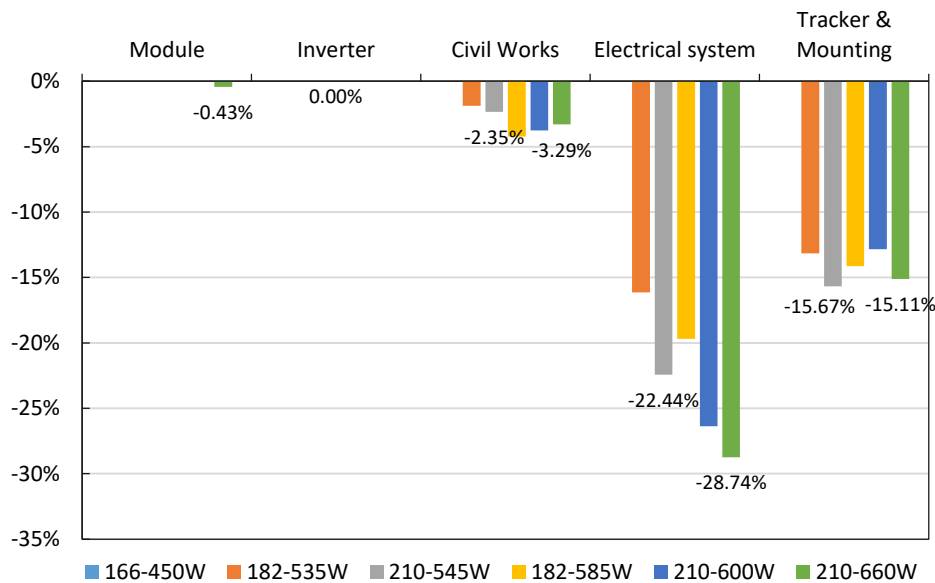


Figure 6 The breakdown of CAPEX in comparison with 166-450W for the 1P tracking PV system in Spain.

The breakdown of CAPEX in comparison with 166-450W is illustrated in Figure 6. Similar as the fixed-tilt PV system in Germany, it shows that the savings of the 1P tracking system also mainly come from the electrical system and tracker & mounting, regardless of the module types. However, the 210-660W module has the highest saving in percentage of over 28% in electrical system and over 15% in tracker & mounting.

### 3.1.3 PV system with 2P tracker in Spain

The another system with a capacity of 50MW in Spain is defined as single-axis tracking with two module row (2P) system. The system uses bifacial modules with central inverters. It is assumed that the site is flat and large enough for the planed plant size. No shading caused by external objects such as buildings or trees are considered in the project. The project assumptions are similar as the 1P tracking system and listed in Table 8.

Table 8 The project assumptions of the 2P tracking PV system in Germany.

Project site	Badajoz, Spain
Annual GHI	1796 kWh/m <sup>2</sup>
Average ambient temperature	17.4 °C
DC capacity	50 MW
Mounting	Single-axis 2P tracker
Inverter	Central inverter

The arrangement of the module and inverter in the analyzed PV system are listed in Table 9. The overall idea of configuring the system is to reach the closest value of DC capacity to 50MW, while the numbers

of inverter and transformer are kept the same for all comparing systems.

*Table 9 The configurations of the 2P tracking PV system in Spain.*

Module Type	166-450W	182-535W	210-545W	182-585W	210-600W	210-660W
Module Power (W)	450	535	545	585	600	660
Module Size (mm)	2102x1040	2256x1133	2384x1096	2411x1134	2172x1303	2384x1303
Inverter	SG3125HV-20					
Modules/String	28	29	38	26	34	31
Strings/Inverter	330	268	201	273	204	203
String power (W)	12.60	15.52	20.71	15.21	20.40	20.46
DC/AC Ratio	1.16	1.16	1.16	1.16	1.16	1.16
Pitch [m]	10.81	11.53	12.17	12.31	11.11	12.17
Strings/Tracker	4	4	3	4	3	3
Tracker number	990	804	804	819	816	812
GCR	40%					
DC Capacity (kW)	49,896	49,896	49,953	49,828	49,939	49,841
AC Capacity (kW)	43,116					
Module numbers	110,880	93,264	91,656	85,176	83,232	75,516
Inverter numbers	12					

*Table 10 The CAPEX and LCOE results of the 2P tracking PV system in Spain.*

Module type	166-450W	182-535W	210-545W	182-585W	210-600W	210-660W
Unit: €/ct/W						
Module	25.87	26.12	26.05	26.64	26.14	25.76
Inverter	3.03	3.03	3.03	3.03	3.03	3.03
Civil works	2.22	2.18	2.18	2.11	2.14	2.14
Electrical system	2.83	2.41	2.25	2.33	2.15	2.08
Tracker & Mounting	12.66	10.92	10.76	10.71	10.74	10.48
<b>CAPEX</b>	<b>51.42</b>	<b>49.48</b>	<b>49.08</b>	<b>49.63</b>	<b>49.01</b>	<b>48.31</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-1.94</b>	<b>-2.34</b>	<b>-1.79</b>	<b>-2.41</b>	<b>-3.11</b>
Land	0.156	0.157	0.152	0.146	0.148	0.149
OPEX	1.02	0.99	0.97	0.99	0.98	0.97
Unit: €/ct/kWh						
<b>LCOE</b>	<b>2.88</b>	<b>2.75</b>	<b>2.73</b>	<b>2.76</b>	<b>2.72</b>	<b>2.68</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.13</b>	<b>-0.15</b>	<b>-0.12</b>	<b>-0.16</b>	<b>-0.20</b>

Table 10 lists the CAPEX and LCOE results of the PV system for the six different modules. The percentage reduction is shown in Figure 7. It indicates that overall the 210 modules have a lower CAPEX and LCOE. Compared with 166-450W module, 210 modules reduce both the CAPEX and LCOE by over 4%, of which 210-660W performs the best, with the highest reduction of 6.05% (3.11 €/ct/W) in CAPEX and 6.94% (0.20 €/ct/kWh) in LCOE.



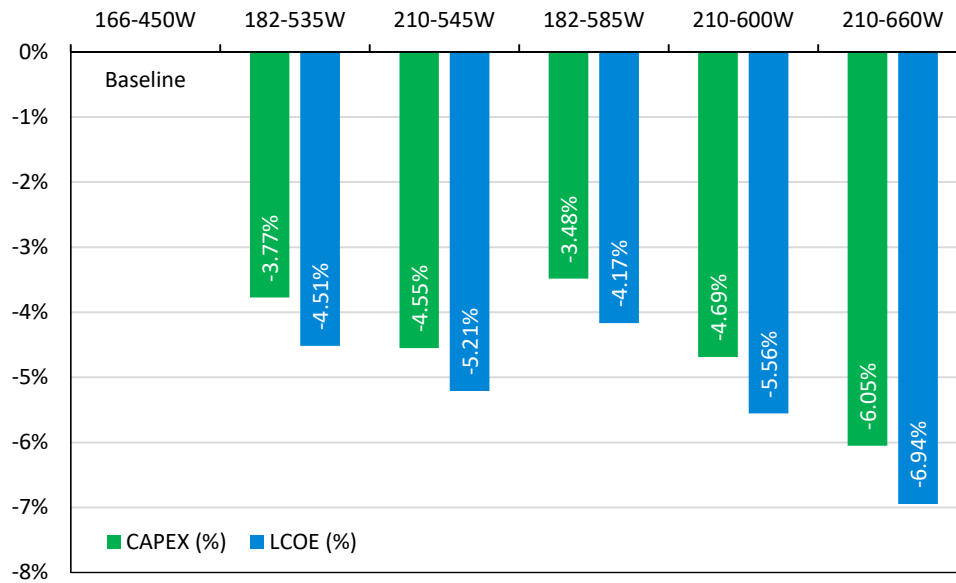


Figure 7 The comparison of CAPEX and LCOE with 166-450W for the 2P tracking PV system in Spain.

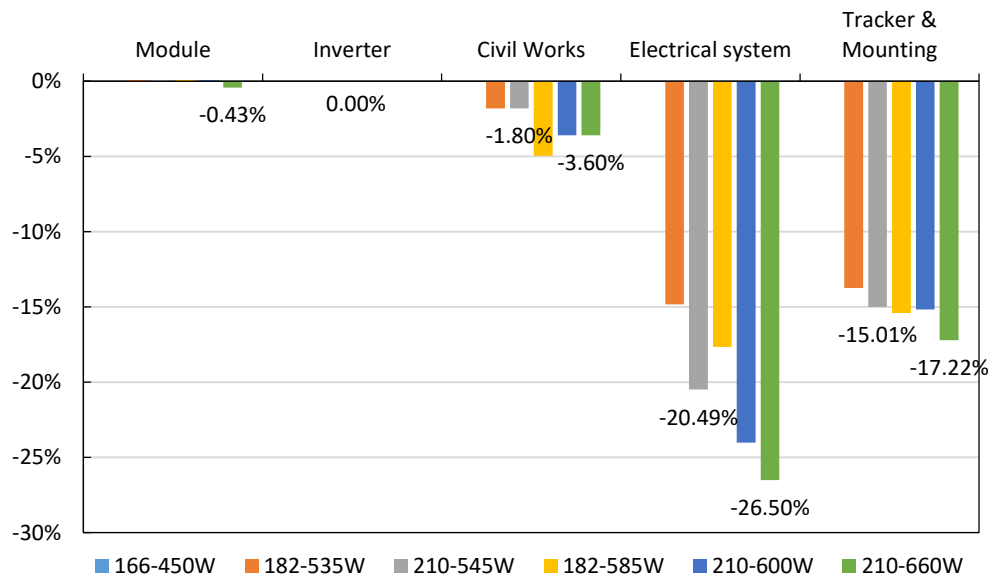


Figure 8 The breakdown of CAPEX in comparison with 166-450W for the 2P tracking PV system in Spain.

The breakdown of CAPEX in comparison with 166-450W is illustrated in Figure 8. It shows that the savings of the 2P tracking system also mainly come from the electrical system and tracker & mounting, regardless of the module types. However, the 210-660W module has the highest saving in percentage of over 26% in electrical system and over 15% in tracker & mounting.

### 3.2 Study on 1P tracking PV system in Spain by DNV

DNV, whose headquarters are in Oslo, Norway, is the world's leading independent assessment organization, with offices worldwide. As an international authority on assurance and risk management, DNV is renowned for its large database, world-leading digital solutions and objectivity.

DNV has conducted an LCOE analysis to compare three different types of modules for an assumed PV plant located in Spain. The three modules are 182-535W, 210-545W, and 210-660W. The designed PV plant is defined as 1P tracking system coupled with string inverter. The project assumptions are listed in Table 11. The arrangement of the module and inverter in the analyzed PV system are listed in Table 12.

*Table 11 Project assumptions of the 1P tracking PV system in Spain.*

Project site	Andalusia, Spain
Annual GHI	1856 kWh/m <sup>2</sup>
Average ambient temperature	18.9 °C
DC capacity	100MW
Mounting	Single-axis 1P tracker
Inverter	String inverter

*Table 12 The configurations of the 1P tracking PV system in Spain.*

Module Type	182-535W	210-545W	210-660W
Module Power (W)	535	545	660
Module efficiency (%)	20.93%	20.86%	21.25%
Inverter	SUNGROW SG250HX		
Modules/String	27	36	30
String number	6956	5106	5106
String power (kW)	14.45	19.62	19.80
DC Power (MW)	100.48	100.18	101.10
AC power (MW)	99.9	99.9	99.9
DC/AC ratio	1.01	1.00	1.01
Module numbers	187,812	183,816	153,180
Inverter numbers	444	444	444
Tracker number	1739	1702	1702
Height of tracker (m)	1.68	1.73	1.73
Row spacing (m)	7.01	7.41	7.41
Land (ha)	165.77	165.78	163.88

Table 13 lists the CAPEX and LCOE results of the designed PV system. The percentage reduction is shown in Figure 9. It indicates that both 210-545W and 210-660W modules have advantages over 182-535W module in terms of CAPEX and LCOE. It is estimate that compared with 182-535W, the CAPEX of 210-660W can be reduced by about 2.05% (1.2 €/ct/W), and the LCOE can be reduced by 2.29% (0.08 €/ct/kWh).

Table 13 The CAPEX and LCOE results of the 1P tracking PV system in Spain.

Module type	182-535W	210-545W	210-660W
Unit: €/W			
Module	0.1932	0.1932	0.1932
Inverter	0.0257	0.0257	0.0257
Tracker*	0.0764	0.0746	0.0696
Transportation**	0.0107	0.0105	0.0096
DC cabling***	0.0070	0.0056	0.0055
<b>CAPEX</b>	<b>0.5860</b>	<b>0.5819</b>	<b>0.5740</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>0.0041</b>	<b>0.0120</b>
OPEX	0.0186	0.0187	0.0185
Unit: €/kWh			
<b>LCOE</b>	<b>0.0350</b>	<b>0.0348</b>	<b>0.0342</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>0.0002</b>	<b>0.0008</b>

\* includes tracker with piles and tracker mounting

\*\* includes transport of module and tracker

\*\*\* includes DC cabling and DC cable mounting

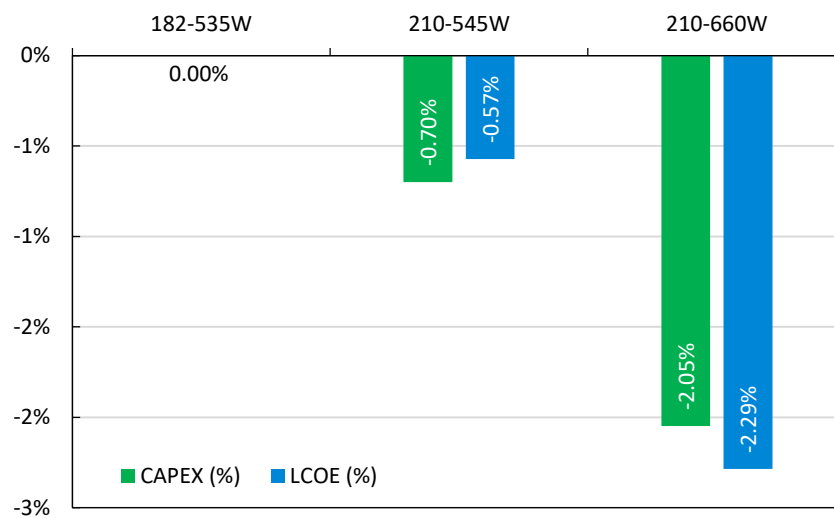


Figure 9 The comparison of CAPEX and LCOE with 182-535W for the 1P tracking PV system in Spain.

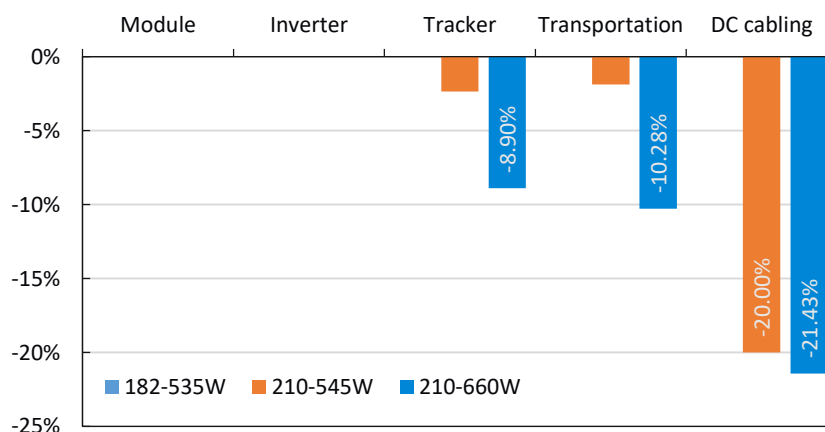


Figure 10 The breakdown of CAPEX in comparison with 182-535W for the 1P tracking PV system in Spain.

A detailed breakdown of CAPEX in percentage reduction is compared in Figure 10. The results show that the savings are mainly owing to three aspects: electrical cables, tracker installation and transportation. Compared to the 182-535W module, the DC cabling, transportation, and tracker of 210-660W module can be reduced by 21.43%, 10.28%, and 8.90%, respectively.

### 3.3 Study on 1P tracking PV system in USA by Black & Veatch

Founded in 1915, Black & Veatch is a global independent services provider to solar projects. Black & Veatch has performed an CAPEX and LCOE assessment for five hypothetical PV projects located in USA for different modules. The project assumptions are listed in Table 14.

*Table 14 The project assumptions of the 1P tracking PV system in USA.*

Project site	Texas, USA
Annual GHI	1865 kWh/m <sup>2</sup>
Average ambient temperature	17.5 °C
AC capacity	100MW
Mounting	Single-axis 1P tracker
Inverter	Central inverter

Table 15 summarizes the major equipment and principal system design parameters for the proposed system. It is assumed that the project site is a rectangular block and are for production modeling purpose only. The simulated CAPEX and LCOE results are shown in Table 16.

*Table 15 The configurations of the 1P tracking PV system in USA.*

Module Type	166-450W	158-480W	182-535W	210-545W	210-660W
Module Power (W)	450	480	535	545	660
Module efficiency (%)	20.38%	20.93%	20.86%	21.20%	21.25%
Inverter	SUNGROW SG3600UD				
Modules/String	27	32	28	36	30
String power (kW)	12.15	15.36	14.98	19.62	19.80
DC capacity factor	23.4%	23.5%	23.6%	23.6%	23.6%
AC capacity factor	29.0%	29.2%	29.3%	29.3%	29.2%
Module numbers	277,803	260,448	233,660	229,392	189,420
Pitch (m)	6.03	6.61	6.44	6.81	6.81
GCR (%)	35.01%	35.02%	35.03%	35.01%	35.00%
Land (ha)	507	501	493	491	486

Table 16 The CAPEX and LCOE results of the 1P tracking PV system in USA.

Module Type	166-450W	158-480W	182-535W	210-545W	210-660W
Unit: USD/W					
Module*	0.3081	0.3075	0.3068	0.3066	0.3055
Inverter	0.0552	0.0552	0.0552	0.0552	0.0552
Rack & post**	0.1620	0.1566	0.1500	0.1481	0.1433
Civil cost	0.0246	0.0243	0.0240	0.0239	0.0236
BOS***	0.0634	0.0589	0.0534	0.0485	0.0422
E&M cost****	0.0803	0.0757	0.0702	0.0687	0.0601
Startup	0.0025	0.0025	0.0025	0.0025	0.0025
Others	0.1343	0.1312	0.1275	0.1249	0.1211
<b>CAPEX</b>	<b>0.8305</b>	<b>0.8120</b>	<b>0.7897</b>	<b>0.7786</b>	<b>0.7535</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0185</b>	<b>-0.0408</b>	<b>-0.0519</b>	<b>-0.0770</b>
Unit: USD/MWh					
<b>LCOE</b>	<b>24.99</b>	<b>24.32</b>	<b>23.59</b>	<b>23.27</b>	<b>22.66</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.67</b>	<b>-1.40</b>	<b>-1.72</b>	<b>-2.33</b>

\* includes module cost and installation cost.

\*\* includes rack & post cost and installation cost.

\*\*\* AC cable, DC cable, PV wire harnesses and combiner boxes, it includes material cost and installation cost.

\*\*\*\* Engineering & management cost.

The reduction of CAPEX and LCOE is compared with 166-450W module, as shown in Figure 11. The results show that the 210mm modules perform the best overall for reducing CAPEX and LCOE among all the module types. The study found that compared to the 166-450W module, the 210-660W module reduce both CAPEX and LCOE by more than 9%. Compared to the 182-535W modules, the 210-660W modules reduce CAPEX up to 4.57% and lower LCOE up to 3.94%.

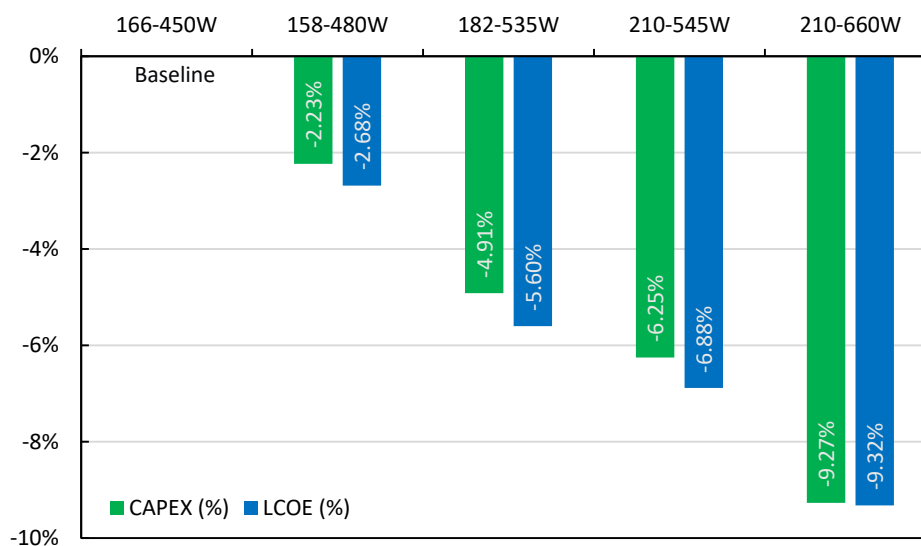


Figure 11 The comparison of CAPEX and LCOE with 166-450W for the 1P tracking PV system in USA.

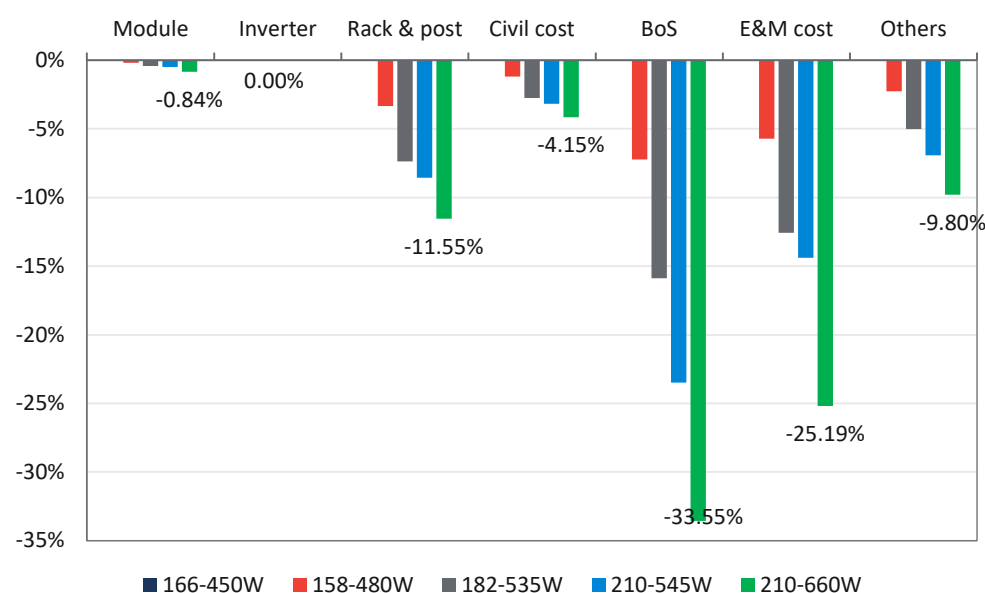


Figure 12 The breakdown of CAPEX in comparison with 166-450W for the 1P tracking PV system in USA.

A detailed breakdown of CAPEX in comparison with 166-450W is shown in Figure 12. The results show that the savings are mainly owing to BOS, E&M cost, Rack & post. If 210-660W module is used for PV system design, the costs for BOS, E&M and Rack & Post can be reduced by 33.55%, 25.19% and 11.55%, respectively, compared to that with 166-450W module.

### 3.4 Study on tracking PV system in Brazil by Enertis Applus+

Enertis Applus+ is a global consulting, engineering, and quality control firm with a track record of more than 15 years and an accumulated experience of more than 135 GW worldwide. It is part of Applus+, one of the world's leading companies in the inspection, testing and certification sector with more than 20 years of experience in the renewable sector. Its mission is to ensure maximum profitability for customers and proper risk management of their projects. With a track-record of 2,500 projects in more than 65 countries, Enertis Applus+ has offices in the United States, Spain, Chile, Mexico, Australia, United Kingdom, Colombia, Panama, Brazil, Argentina, South Africa, and China.

Enertis Applus+ has conducted the comparative study to determine the CAPEX and LCOE of the ultra-high-power 210 modules from Trina Solar, and compared the results with 166 and 182 modules. In the study, three different PV plants were examined with different project sizes, mounting methods, and inverters, as shown in Table 17.



Table 17 The three plant configurations in the study conducted by Enertis Applus+.

Item	Plant 1	Plant 2	Plant 3
AC capacity	5 MW	100 MW	100 MW
Mounting	1P tracker	2P tracker	2P tracker
Inverter	String inverter	String inverter	Central inverter
Module type	166-450W, 182-535W, 210-545W, 210-600W, 210-660W		
Project site	Minas Gerais, Brazil		

The project is located in Brazil, approximately 4 km northwest of the community of Pirapora, in the state of Minas Gerais. The location and available land for the designed PV system is shown in Figure 13.



Figure 13 The location and available land for the PV projects in Brazil.

The main climatological features of the project site are shown in Figure 14. The project site has a yearly global horizontal irradiance (GHI) of 2034 kWh/m<sup>2</sup> with the highest GHI in October (187.14 kWh/m<sup>2</sup>) and the lowest in June (141.62 kWh/m<sup>2</sup>). The monthly average temperature is in the range of 21.51-25.41°C.

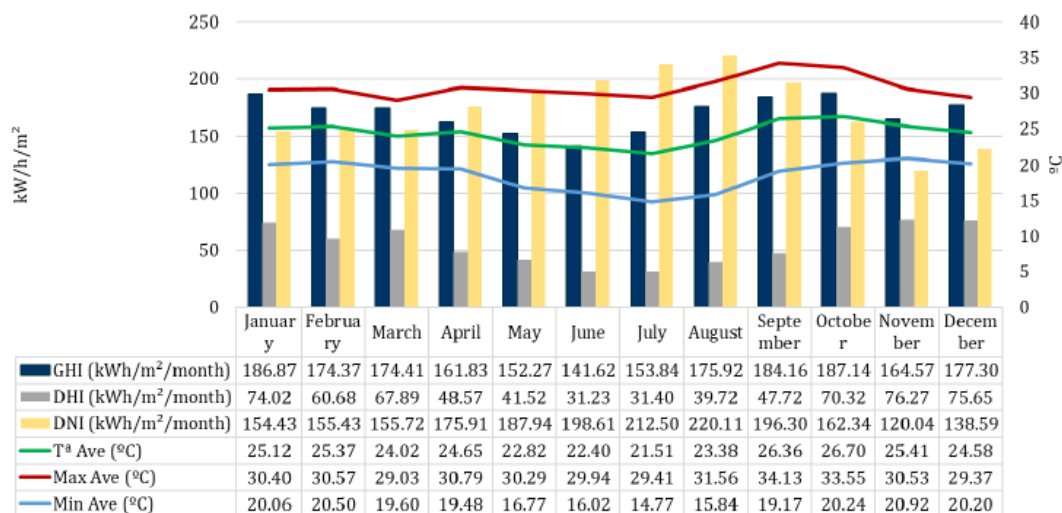


Figure 14 The main climatological features on the PV project's site in Brazil.

### 3.4.1 PV system with 1P tracker and string inverter in Brazil

The first designed PV system with a capacity of 5MW is defined as single-axis 1P tracking system with string inverter. The project assumptions are listed in Table 18. The arrangement of the module and inverter for the analyzed PV system is listed in

Table 19.

*Table 18 The project assumptions of the 1P tracking PV system with string inverter in Brazil.*

Project site	Minas Gerais, Brazil
Annual GHI	2034 kWh/m <sup>2</sup>
Average ambient temperature	24.36 °C
AC capacity	5 MW
Mounting	Single-axis 1P tracker
Inverter	String inverter

*Table 19 The configurations of the 1P tracking PV system with string inverter in Brazil.*

Module Type	166-450W	182-535W	210-545W	210-600W	210-660W
Module Power (W)	450	535	545	600	660
Module efficiency (%)	20.38%	20.93%	20.86%	21.2%	21.25%
Inverter	SUN2000-215KTL				
Modules/String	30	30	40	36	33
String number	484	404	299	301	299
String power (kW)	13.50	16.05	21.80	21.60	21.78
DC Power (MW)	6.53	6.48	6.52	6.50	6.51
AC power (MW)	5.31				
DC/AC ratio	1.23	1.22	1.23	1.22	1.23
Module numbers	14,520	12,120	11,960	10,836	9,867
Inverter numbers	26				
Tracker number	121	101	100	101	100
Tracker power (kW)	54.00	64.20	65.40	64.80	65.34
Pitch (m)	5.53	6.15	6.42	5.96	6.51
String per tracker	4	4	3	3	3
GCR (%)	38.17%	36.88%	37.13%	36.44%	36.62%
Land (ha)	10				

*Table 20 The CAPEX and LCOE results of the 1P tracking PV system with string inverter in Brazil.*

Module type	166-450W	182-535W	210-545W	210-600W	210-660W
Unit: USD/W					
Module	0.2584	0.2571	0.2570	0.2563	0.2558
Tracker	0.0863	0.0758	0.0733	0.0764	0.0729
Inverter	0.0389	0.0392	0.0390	0.0391	0.0391
Transportation &	0.0065	0.0059	0.0058	0.0056	0.0054

Logistics					
Civil works	0.1195	0.1134	0.1130	0.1126	0.1133
Electrical system	0.0242	0.0237	0.0206	0.0207	0.0206
<b>CAPEX</b>	<b>0.6987</b>	<b>0.6805</b>	<b>0.6732</b>	<b>0.6756</b>	<b>0.6717</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0182</b>	<b>-0.0255</b>	<b>-0.0231</b>	<b>-0.0270</b>
OPEX	0.02155	0.02164	0.02158	0.02161	0.02159
Unit: USD/MWh					
<b>LCOE</b>	<b>37.01</b>	<b>36.05</b>	<b>35.72</b>	<b>35.61</b>	<b>35.52</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.96</b>	<b>-1.29</b>	<b>-1.40</b>	<b>-1.49</b>

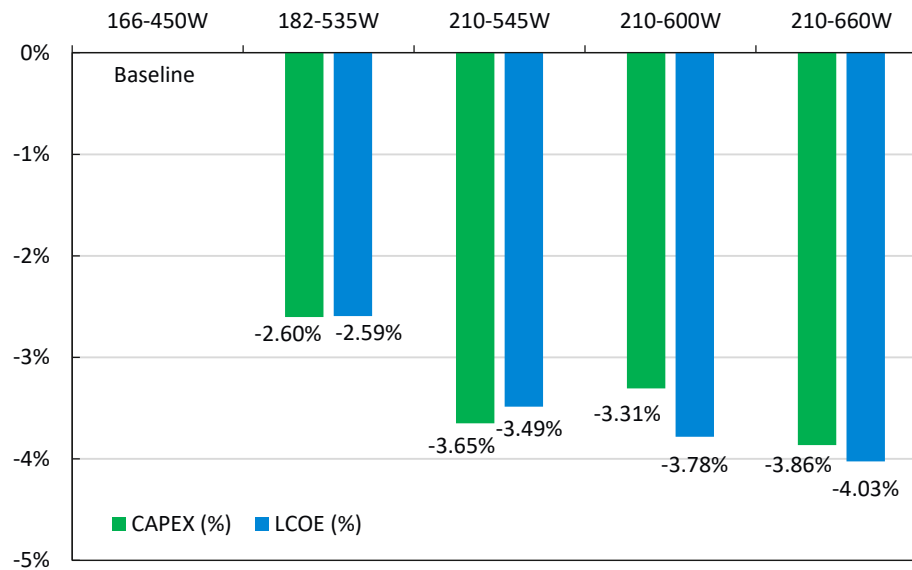


Figure 15 The comparison of CAPEX and LCOE with 166-450W for the 1P tracking PV system with string inverter in Brazil.

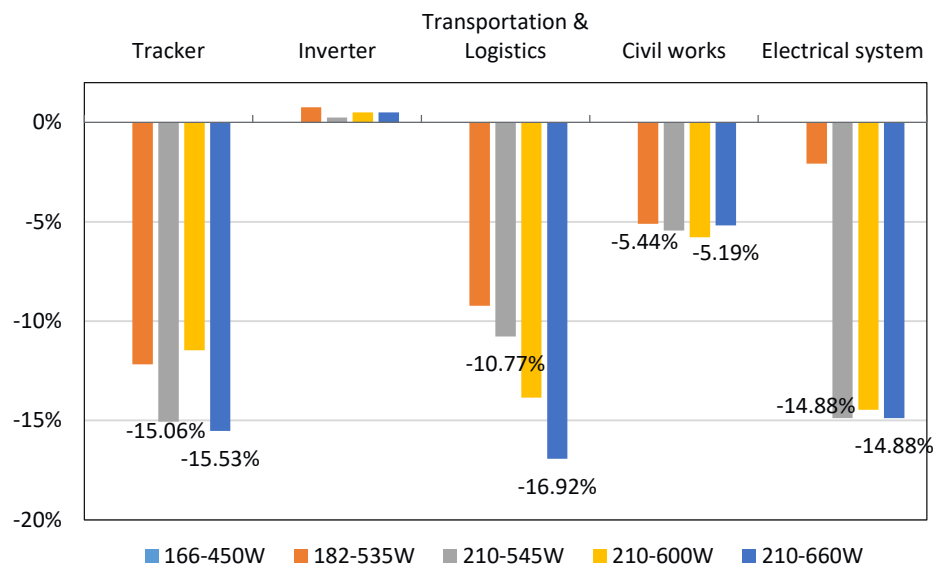


Figure 16 The breakdown of CAPEX in comparison with 166-450W for the 1P tracking PV system with string inverter in Brazil.

Table 20 lists the CAPEX and LCOE results of the designed PV system for the five different modules. The reduction in percentage of CAPEX and LCOE is shown in Figure 15. It indicates that overall the 210 modules have a lower CAPEX and LCOE. With respect to the 166-450W module, 210 modules are able to reduce both the CAPEX and LCOE by over 3%, of which 210-660W performs the best with the highest reduction of 3.86% (0.027 USD/W) in CAPEX and 4.03% (1.49 USD/MWh) in LCOE.

The breakdown of CAPEX in comparison with 166-450W is illustrated in Figure 16. It clearly shows that the savings of using 210 modules mainly come from three aspects: tracker, transportation & logistics, and electricity system. Compared to all other modules, 210-660W module has the best performance, with the highest saving of 15.53% in tracker, 16.92% in transportation & logistics, and 14.88% in electrical system.

### 3.4.2 PV system with 2P tracker and string inverter in Brazil

The first designed PV system with a capacity of 100MW is defined as single-axis 2P tracking system with string inverter. The project assumptions are listed in Table 21. The arrangement of the module and inverter for the analyzed PV system is listed in Table 22.

*Table 21 The project assumptions of the 2P tracking PV system with string inverter in Brazil.*

Project site	Minas Gerais, Brazil
Annual GHI	2034 kWh/m <sup>2</sup>
Average ambient temperature	24.36 °C
AC capacity	100 MW
Mounting	Single-axis 2P tracker
Inverter	String inverter

*Table 22 The configurations of the 2P tracking PV system with string inverter in Brazil.*

Module Type	166-450W	182-535W	210-545W	210-600W	210-660W
Module Power (W)	450	535	545	600	660
Module efficiency (%)	20.38%	20.93%	20.86%	21.2%	21.25%
Inverter	SUN2000-215KTL				
Modules/String	30	30	40	34	33
String number	9632	8120	5876	6390	5988
String power (kW)	13.50	16.05	21.80	20.40	21.78
DC Power (MW)	129.8	130.0	130.0	130.0	130.1
AC power (MW)	104.39				
DC/AC ratio	1.24	1.25	1.25	1.25	1.25
Module numbers	288,360	243,000	238,440	216,750	197,109
Inverter numbers	504				
Tracker number	2408	2030	1992	2130	1996
Tracker power (kW)	54.00	64.20	65.40	61.20	65.34

Pitch (m)	11.60	12.77	13.45	12.46	13.56
String per tracker	4	4	3	3	3
GCR (%)	36.53%	35.44%	35.56%	34.98%	35.26%
Land (ha)	195				

Table 23 The CAPEX and LCOE results of the 2P tracking PV system with string inverter in Brazil.

Module type	166-450W	182-535W	210-545W	210-600W	210-660W
Unit: USD/W					
Module	0.2584	0.2571	0.2570	0.2563	0.2558
Tracker	0.0901	0.0786	0.0773	0.0791	0.0748
Inverter	0.0379	0.0378	0.0378	0.0378	0.0378
Transportation & Logistics	0.0065	0.0058	0.0058	0.0057	0.0054
Civil works	0.0714	0.0683	0.0688	0.0692	0.0686
Electrical system	0.0309	0.0280	0.0258	0.0269	0.0258
<b>CAPEX</b>	<b>0.6181</b>	<b>0.5979</b>	<b>0.5943</b>	<b>0.5970</b>	<b>0.5899</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0202</b>	<b>-0.0238</b>	<b>-0.0211</b>	<b>-0.0282</b>
OPEX	0.01300	0.01299	0.01300	0.01299	0.01299
Unit: USD/MWh					
<b>LCOE</b>	<b>29.99</b>	<b>29.05</b>	<b>28.80</b>	<b>28.95</b>	<b>28.57</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.94</b>	<b>-1.19</b>	<b>-1.04</b>	<b>-1.42</b>

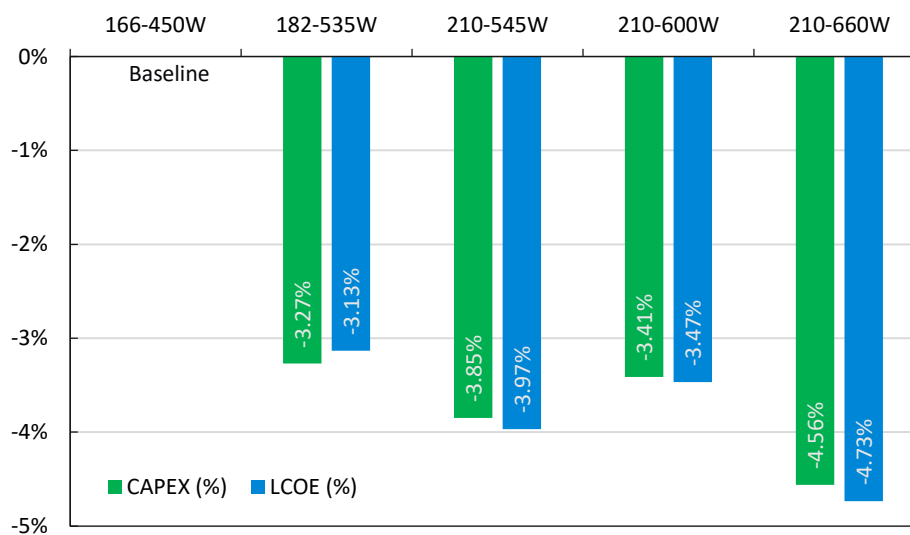


Figure 17 The comparison of CAPEX and LCOE with 166-450W for the 2P tracking PV system with string inverter in Brazil.

Table 23 lists the CAPEX and LCOE results of the designed PV system for the five different modules. The reduction in percentage of CAPEX and LCOE is shown in Figure 17. The results indicate that overall the 210 modules have a lower CAPEX and LCOE. With respect to the 166-450W module, 210 modules are able to reduce both the CAPEX and LCOE by over 3%, of which 210-660W performs the best with the

highest reduction of 4.56% (0.0282 USD/W) in CAPEX and 4.73% (1.42 USD/MWh) in LCOE.

The breakdown of CAPEX in comparison with 166-450W is illustrated in Figure 18. It clearly shows that the savings of using 210 modules mainly come from three aspects: tracker, transportation & logistics, and electricity system. Compared to all other modules, 210-660W module has the best performance, with the highest saving of 16.98% in tracker, 16.92% in transportation & logistics, and 16.50% in electrical system.

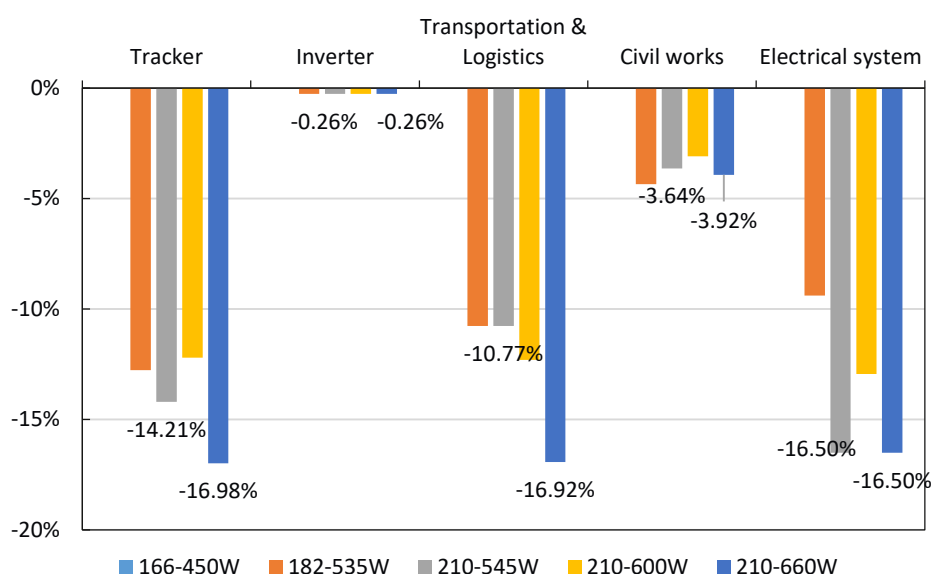


Figure 18 The breakdown of CAPEX in comparison with 166-450W for the 2P tracking PV system with string inverter in Brazil.

### 3.4.3 PV system with 2P tracker and central inverter in Brazil

The first designed PV system with a capacity of 100MW is defined as single-axis 2P tracking system with central inverter. The project assumptions are listed in Table 24. The arrangement of the module and inverter for the analyzed PV system is listed in Table 25.

Table 24 The project assumptions of the 2P tracking PV system with central inverter in Brazil.

Project site	Minas Gerais, Brazil
Annual GHI	2034 kWh/m <sup>2</sup>
Average ambient temperature	24.36 °C
AC capacity	100 MW
Mounting	Single-axis 2P tracker
Inverter	central inverter

Table 25 The configurations of the 2P tracking PV system with central inverter in Brazil.

Module Type	166-450W	182-535W	210-545W	210-600W	210-660W
Module Power (W)	450	535	545	600	660
Module efficiency (%)	20.38%	20.93%	20.86%	21.2%	21.25%



Inverter	SMA SC 4600 UP				
Modules/String	30	30	40	34	33
String number	9612	8100	5916	6375	5973
String power (kW)	13.50	16.05	21.80	20.40	21.78
DC Power (MW)	129.8	130.0	130.0	130.0	130.1
AC power (MW)	104.39				
DC/AC ratio	1.24	1.25	1.25	1.25	1.25
Module numbers	288,360	243,000	238,440	216,750	197,109
Inverter numbers	23				
Tracker number	2403	2025	1987	2125	1991
Tracker power (kW)	54.00	64.20	65.40	61.20	65.34
Pitch (m)	11.60	12.77	13.45	12.46	13.56
String per tracker	4	4	3	3	3
GCR (%)	36.53%	35.44%	35.56%	34.98%	35.26%
Land (ha)	195				

Table 26 The CAPEX and LCOE results of the 2P tracking PV system with central inverter in Brazil.

Module type	166-450W	182-535W	210-545W	210-600W	210-660W
Unit: USD/W					
Module	0.2584	0.2571	0.2570	0.2563	0.2558
Tracker	0.0901	0.0786	0.0773	0.0791	0.0748
Inverter	0.0449	0.0448	0.0448	0.0448	0.0448
Transportation & Logistics	0.0065	0.0058	0.0057	0.0056	0.0053
Civil works	0.0735	0.0704	0.0705	0.0711	0.0706
Electrical system	0.0313	0.0286	0.0267	0.0270	0.0262
<b>CAPEX</b>	<b>0.6208</b>	<b>0.6002</b>	<b>0.5959</b>	<b>0.5982</b>	<b>0.5913</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0206</b>	<b>-0.0249</b>	<b>-0.0226</b>	<b>-0.0295</b>
OPEX	0.01390	0.01389	0.01389	0.01389	0.01388
Unit: USD/MWh					
<b>LCOE</b>	<b>30.91</b>	<b>29.92</b>	<b>29.67</b>	<b>29.75</b>	<b>29.43</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.99</b>	<b>-1.24</b>	<b>-1.16</b>	<b>-1.48</b>

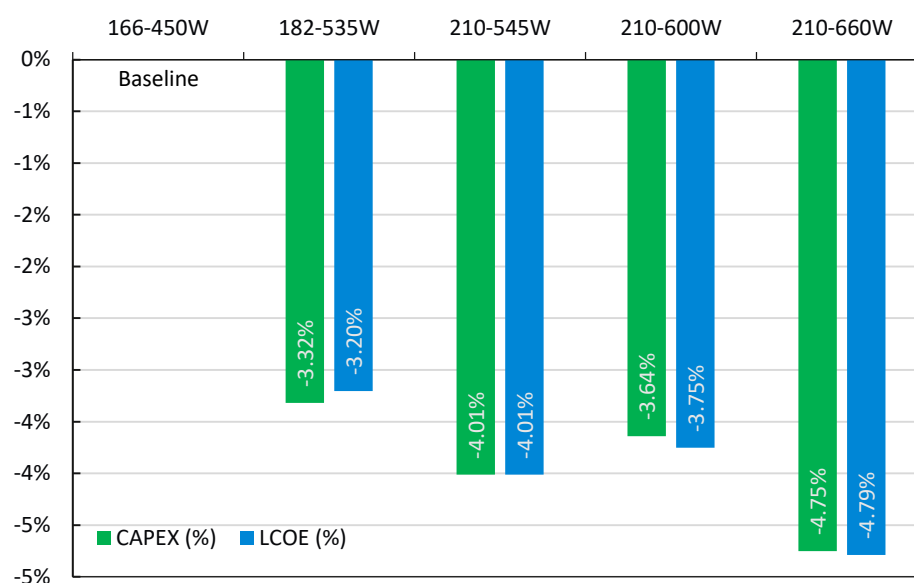


Figure 19 The comparison of CAPEX and LCOE with 166-450W for the 2P tracking PV system with central inverter in Brazil.

Table 26 lists the CAPEX and LCOE results of the designed PV system for the five different modules. The reduction of CAPEX and LCOE is shown in Figure 19. It indicates that overall the 210 modules have a lower CAPEX and LCOE. With respect to the 166-450W module, 210 modules are able to reduce both the CAPEX and LCOE by over 3%, of which 210-660W performs the best with the highest reduction of 4.75% (0.0295 USD/W) in CAPEX and 4.79% (1.48 USD/MWh) in LCOE.

The breakdown of CAPEX in comparison with 166-450W is illustrated in Figure 20. It clearly shows that the savings of using 210 modules mainly come from three aspects: tracker, transportation & logistics, and electricity system. Compared to all other modules, 210-660W module has the best performance, with the highest saving of 16.98% in tracker, 18.46% in transportation & logistics, and 16.29% in electrical system.

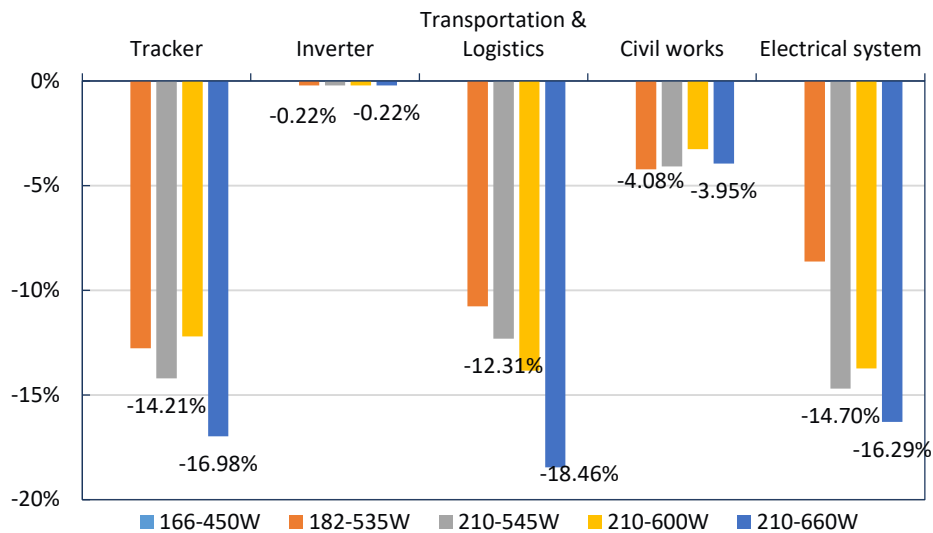


Figure 20 The breakdown of CAPEX in comparison with 166-450W for the 2P tracking PV system with central inverter in Brazil.

### 3.5 Study on 1P tracking PV systems in Australia and UAE by UL

UL (Underwriters Laboratories), a company with more than 120 years of expertise in bringing clarity and empowering trust to support the responsible design, production, marketing and purchase of the goods, solutions, and innovations.

UL has recently carried out a study on the assessment of CAPEX and LCOE of solar PV systems located in Australia and UAE with two different modules (182-540W and 210-660W). The solar systems in Australia and UAE are designed with the same DC capacity of 125MW, 1P tracker installation coupled with central inverter. The configurations of the two systems are listed in Table 27.

Table 27 The two plant configurations in the study conducted by UL.

Item	Plant 1	Plant 2
DC capacity	125 MW	125 MW
Mounting	Single-axis 1P tracker	Single-axis 1P tracker
Module	182-540W, 210-660W	182-540W, 210-660W
Inverter	Central inverter	Central inverter
Project site	New South Wales, Australia	Dubai, UAE

#### 3.5.1 PV system with 1P tracker in Australia

Maryvale, New South Wales, Australia (32.44°S, 148.93°E) is selected for the study (Figure 21). The town is located in Central West Orana Renewable Energy Zone (REZ) that was formally declared in 2021 as one of five designated clean energy areas. Table 28 includes the summary of the main characteristics of the project.



Figure 21 Aerial view of the project location in Australia.

UL have done a desktop design of a 125 MW<sub>DC</sub> solar PV plant using generic 182-540W and 210-660W bifacial PV modules, NEXTracker NX Horizon single axis 1P trackers, SMA central inverters, and based on typical configurations. The DC/AC ratio and ground cover ratio were considered to be the same to maintain consistency in bifacial gain and shading losses. The characteristics of the project design is shown in Table 29.

Table 28 The project assumptions of the 1P tracking PV system in Australia.

Project site	Maryvale, New South Wales, Australia
Annual GHI	1904 kWh/m <sup>2</sup>
Average ambient temperature	17.1°C
DC capacity	125 MW
Mounting	Single-axis 1P tracker
Inverter	Central Inverter

Table 29 The configurations of the 1P tracking PV system in Australia.

Module Type	182-540W	210-660W
Module Power (W)	540	660
Module efficiency (%)	20.9%	21.2%
Inverter	SMA SC4000 UP	SMA SC4000 UP
Modules/String	28	30
String number	8288	6328
String power (kW)	15.12	19.80
DC Power (MW)	125.3	125.3
AC power (MW)	100.8	100.8
DC/AC ratio	1.24	1.24
Module numbers	232064	189840
Inverter numbers	28	28
Tracker number	2688/112	2072/56

Tracker power (kW)	45.36/30.24	55.44/36.96
String per tracker	3/2	3/2
Pitch (m)	6.5	6.8
Land (ha)	183	177

Table 30 The CAPEX and LCOE results of the 1P tracking PV system in Australia.

Module type	182-540W	210-660W
Unit: USD/W		
PV Modules	0.2494	0.2494
Inverter Station Equipment	0.0495	0.0495
Trackers	0.0708	0.0637
String Cable 4sqmm	0.0030	0.0018
String Cable 6sqmm	-	0.0012
Combiner Box	0.0074	0.0071
DC Cable 400sqmm	0.0093	0.0096
MV Switchgear & Protection	0.0007	0.0007
Civil Works	0.0997	0.0965
Labor	0.2861	0.2862
Design & Engineering	0.0997	0.0998
Modules Logistics & Shipping	0.0191	0.0174
Development Cost	0.0642	0.0622
DC BOS cost*	0.0905	0.0835
DC BOS cost comp.	BL	0.0069
<b>CAPEX</b>	<b>0.9590</b>	<b>0.9451</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0138</b>
Unit: USD/MWh		
<b>LCOE</b>	<b>64.40</b>	<b>63.50</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.90</b>

\* DC BOS cost includes trackers, string cables, combiner box and DC cables.

Table 30 lists the CAPEX and LCOE results of the PV system with the two modules. It shows that the DC BOS cost of the plant with 210-660W module is 7.70% (0.007 USD/W) lower than the one with 182-540W module, and the overall CAPEX and LCOE are 1.50% (0.014 USD/W) and 1.32% (0.90 USD/MWh) lower, respectively, in comparison with the plant with 182-540W module.

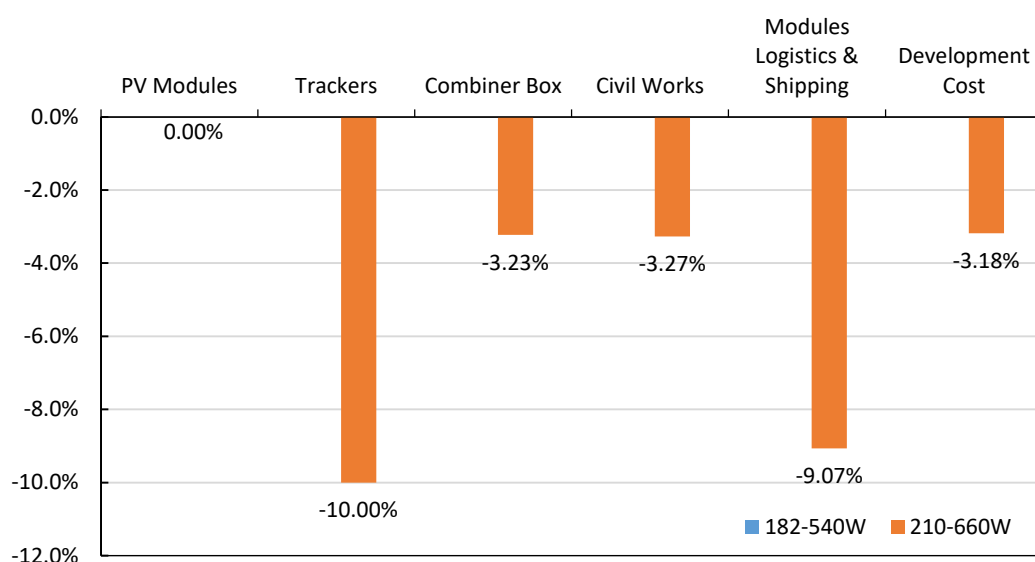


Figure 22 The breakdown of CAPEX in comparison with 182-540W for the 1P tracking PV system in Australia.

The breakdown of CAPEX in comparison with 182-540W is illustrated in Figure 22. It shows that the savings of using 210 modules mainly come from trackers and module logistics and shipping. Compared to the 182-540W module, the plant using 210-660W module is able to reduce 10% and 9.07% in tracker and module logistics & shipping, respectively.

### 3.5.2 PV system with 1P tracker in UAE

The UAE 125-MW solar PV plant is located about 50 km south of the city of Dubai, United Arab Emirates with coordinates of 24.72°N, 55.34°E. It is situated at Mohammed bin Rashid Al Maktoum (MBR) Solar Park (Figure 23), which is one of the world's largest renewable solar parks with a total capacity of 3000 MW. Table 31 includes the summary of the main characteristics of the project.

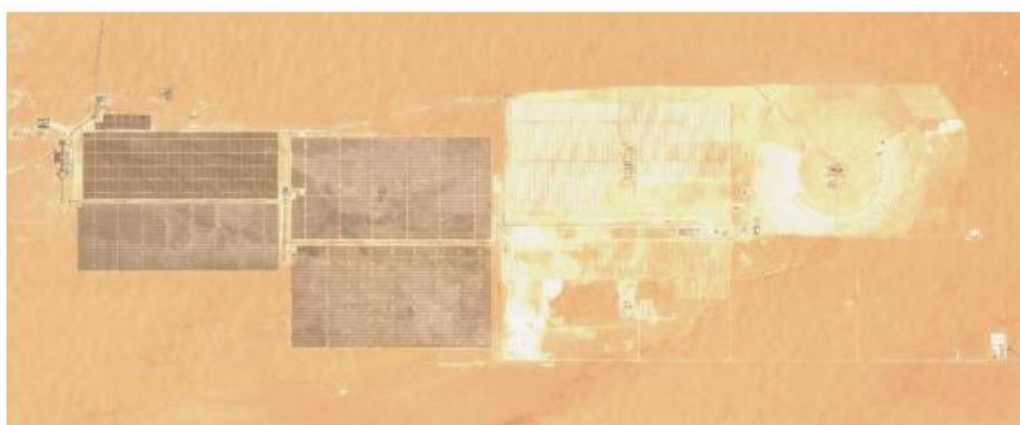


Figure 23 The aerial view of MBR solar park in UAE.

Table 31 The project assumptions of the 1P tracking PV system in UAE.

Project site	Dubai, United Arab Emirates
Annual GHI	2196 kWh/m <sup>2</sup>
Average ambient temperature	28.6 °C
DC capacity	125 MW
Mounting	Single-axis 1P tracker
Inverter	Central Inverter

Table 32 The CAPEX and LCOE results of the 1P tracking PV system in UAE.

Module type	182-540W	210-660W
	Unit: USD/W	
PV Modules	0.2394	0.2394
Inverter	0.0252	0.0253
Trackers	0.0903	0.0842
String Cable 4sqmm	0.0032	0.0019
String Cable 6sqmm	-	0.0013
Combiner Box	0.0054	0.0052
DC Cable 400sqmm	0.0097	0.0101
AC side LV & MV equipment	0.0345	0.0345
Civil Works	0.0898	0.0868
Labor	0.0670	0.0670
Design & Engineering	0.0997	0.0998
Logistics & Shipping	0.0419	0.0398
Inverter Shipping	0.0009	0.0009
Development Cost	0.0725	0.0702
DC BOS cost	0.1085	0.1026
DC BOS cost comp.	BL	-0.0060
<b>CAPEX</b>	<b>0.7795</b>	<b>0.7663</b>
<b>CAPEX comp.</b>	<b>BL</b>	<b>-0.0132</b>
	Unit: USD/MWh	
<b>LCOE</b>	<b>17.80</b>	<b>17.60</b>
<b>LCOE comp.</b>	<b>BL</b>	<b>-0.20</b>

Table 32 lists the CAPEX and LCOE results of the PV system for the two different modules. It shows that the DC BOS cost of the plant with 210-660W module is 5.50% (0.006 USD/W) lower than the one with 182-540W module, and the overall CAPEX and LCOE are 1.70% (0.0132 USD/W) and 1.19% (0.20 USD/MWh) lower, respectively, in comparison with the plant with 182-540W module.

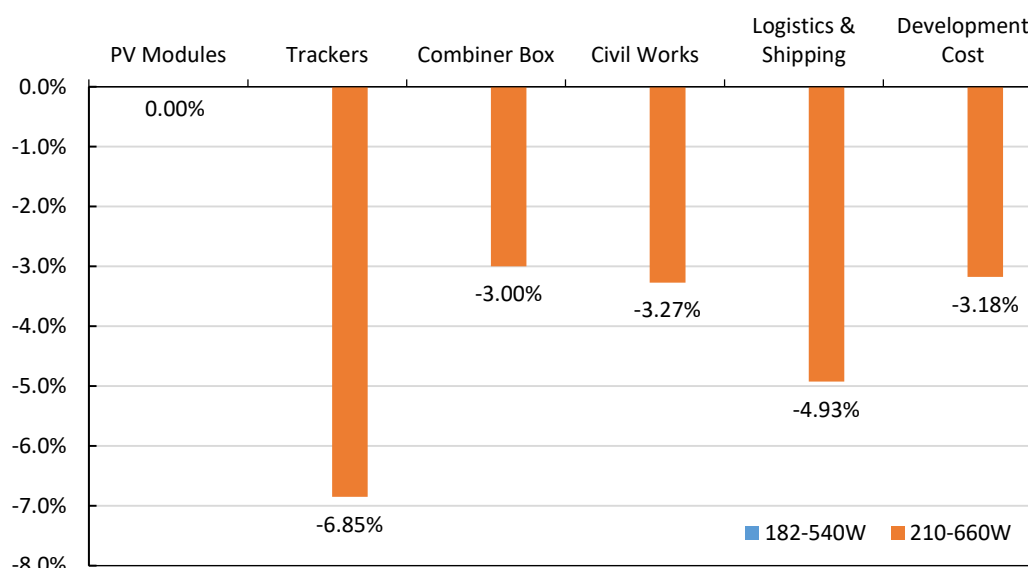


Figure 24 The breakdown of CAPEX in comparison with 182-540W for the 1P tracking PV system in UAE.

The breakdown of CAPEX in comparison with 182-540W is illustrated in Figure 24. It shows that the savings of using 210 modules mainly come from trackers (6.85%) and logistics & shipping (4.93%). In addition, the plant using 210-660W module also reduces the other costs of more than 3%, including combiner box, civil works, and development cost.

### 3.6 Conclusions

In conclusion, the 210mm modules have the characteristics of high module power, high efficiency, low voltage and high string power, which contribute to their significant advantages over 182mm modules and 166 modules in terms of the CAPEX and LCOE. The results revealed that the 210mm modules hold significant advantages in terms of costs in the electrical systems, transportation and tracker installation. In the era of grid parity of solar energy, the 210mm modules represented by Trina Solar Vertex 670W module established a ground-breaking standard for the PV system cost reduction, and the spread of this standard will maximize the customer's value and therefore accelerates the emergence of carbon neutral era.

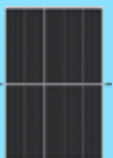
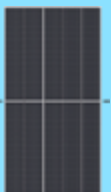
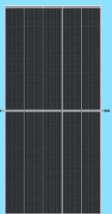

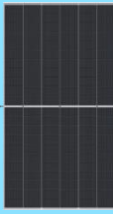


## 4 Introduction of Trina Solar Vertex Module

Trina Solar's Vertex series photovoltaic modules include two type of products: monofacial backsheet and bifacial dual-glass modules, both with 210-mm solar cells. Vertex modules can be widely used in utility-scale, commercial & industrial (C&I) and residential scenarios and their power output can reach a maximum of 670 W, as shown in Table 33.

Conventional photovoltaic modules typically use 6×10 or 6×12 layouts, but Trina Solar has creatively introduced the additional 5×8, 5×10, 5×11, 6×10, and 6×11 layouts for Vertex modules based on the characteristics of 210-mm silicon wafers. These layout designs can balance the electrical performance parameters, optimize area and weight, improve installation compatibility and design, and avoid additional costs increase and supply constraints of key materials such as glass.

*Table 33 The Vertex modules currently available for sale from Trina Solar.*

Module type	Vertex S DE09 series	Vertex DEx18 series	Vertex DEx19 series	Vertex DEx20 series	Vertex DEx21 series
Layout design	5x8	5x10	5x11	6x10	6x11
Dimensions (mm)	1754×1096	2187×1102	2384×1096	2172×1303	2384×1303
Power range	390–410 W	485–510 W	530–555 W	580–605 W	635–670 W
Applications	Residential, C&I	Residential, C&I	All scenarios	All scenarios	All scenarios
Module picture					

## References

This whitepaper directly quoted the contents from the original study reports written by the third-party institutes, no misinterpreting of their original meaning of texts or sentences.

- [1] *Benchmarking and Assessment of the LCOE of Photovoltaic Systems with Different Module Concepts at Germany and Spain*, 16.09.2021, Fraunhofer Institute for Solar Energy System ISE.
- [2] *Trina Vertex One-in-Portrait BOS and LCOE Calculation*, 13.09.2021, DNV.
- [3] *Trina Solar Levelized Cost of Energy Study*, 28.09.2021, Black & Veatch.
- [4] *Estimation of CAPEX, OPEX and LCOE for Several Design Alternatives for a PV Plant in Brazil*, 26.08.2021, Enertis Applus+.
- [5] *LCOE Assessment for Solar PV Modules: Assessment of 540Wp and 660Wp Solar Modules for Projects in Australia and UAE*, 10.01.2022, UL.



Please scan the following QR code for more information:



Project design tool



Product info