Techno-Economic Analysis of GTC Bifacial versus Monofacial Panels

Prof. Cem Avcı & Prof. Gürkan Kumbaroğlu
Boğaziçi University Energy Policy Research Center

Executive Summary

Various scientific studies have tested the bifacial energy gain from solar panels under different system configurations, climate and ground reflection conditions. Depending on these conditions, the bifacial energy gain was found to be in the range of 10-45%. As in the literature cases, GTC bifacial panels were tested and found to outperform standard mono faced panels according to qualification test results by various internationally certified and accredited laboratories. The panels are verified by independent testing laboratories to be in Compliance with the safety and design qualification requirements, class A in both spread of flame and burning brand, long lifetime and high efficiencies yielding high bifacial energy gains.

An economic analysis is performed for a solar farm with 35 MWe installed capacity using bifacial double glass **GTC** Mono-PERC solar panels. Electricity price assumptions are based on the feed-in-tariff for solar power under the Renewable Energy Support Scheme (YEKDEM) for the first 10 years of operation, followed by a Monte Carlo simulation with varying assumptions on the underlying probability distribution based on historical data.

The economic analysis for the bifacial double glass **GTC** Mono-PERC solar panels is compared with standard monofacial Mono-PERC solar panels at the same installed capacity level. The comparison showed that the bifacial panel investment yields significant income throughout the project lifetime. In terms of Net Present Value, the GTC bifacial panels yield $112.6 million whereas $100.3 million is attained by monofacial systems. A $12.3 million additional net profit is generated with an additional expenditure of $3.5 million. In terms of Internal Rate of Return, it is found that the incremental investment on the GTC bifacial panels brings an incremental return of 45.2% in addition to locally produced monofacial panels.

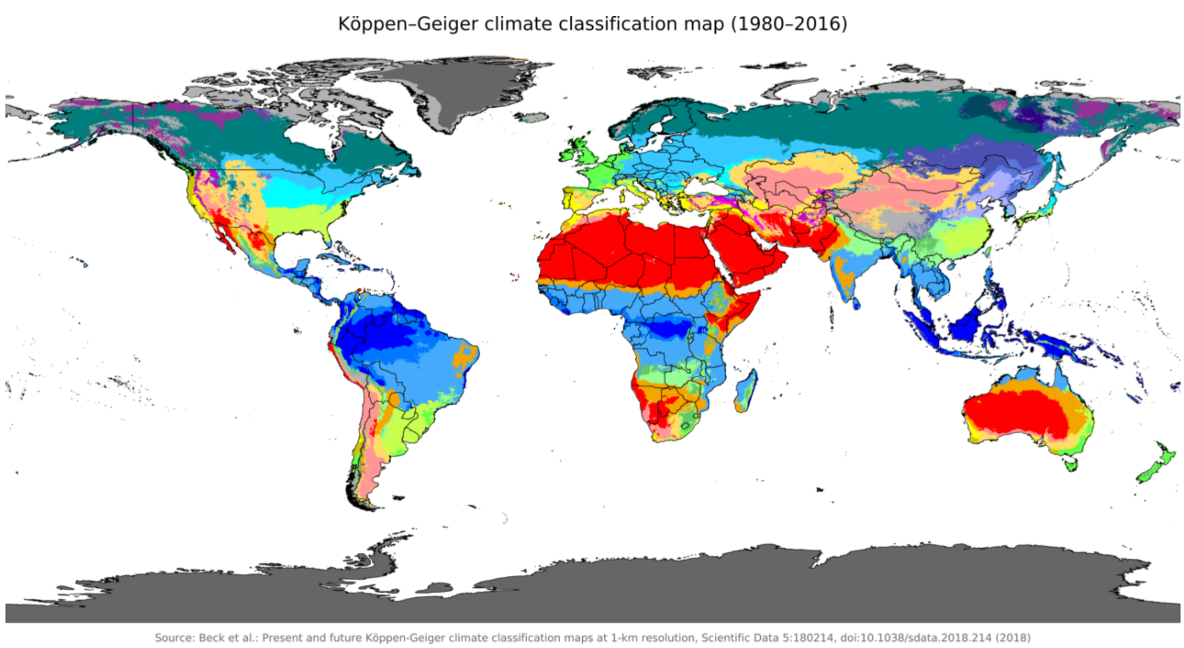
A sensitivity analysis is carried out under different assumptions for discount rate, electricity prices and economic lifetime. It is found that the results are highly sensitive to the discount rate and lifetime, and less sensitive to prices. At the same discount rate and lifetime, GTC panels yield NPVs that are around 10% higher than others, which is even true when the electricity produced by bifacial GTC panels is sold at the lower price. The sensitivity analysis is done with varying assumptions for lifetime, discount rate and electricity prices. All calculations for the bifacial GTC and monofacial panels are repeated under each of the assumptions. The comparison of bifacial GTC versus monofacial panels yielding around 10% difference in NPV is done for the range of computations using each set of assumptions.

In summary the present study showed that double glass bifacial **GTC** solar panels are superior to standard monofacialpanels in multiple aspects; namely endurance and lifetime, maintenance, fire resistance and most importantly electricity production capacity. Based on our analysis, it is also understood that GTC panels are to be considered "NATIONAL AND LOCAL" (Milli ve Yerli) with the local technology developed and manufactured by local engineers in Adıyaman Turkey, and especially with the expected addition of a cell production facility in Fall of 2020 in Bor, Nigde.

1. Literature Review

The International Technology Roadmap for Photovoltaics (ITRPV, 2020) predicts a global market share of 70% for bifacial photovoltaic (PV) modules by 2030. The scientific literature includes vast research on the performance of bifacial solar panel arrays based on analyses conducted at various sites worldwide. Findings, however, are highly location-specific as climate parameters significantly affect the efficiency of solar power generation.

While climate conditions in Turkey vary significantly from one region to another, areas located in southern Turkey have a solar irradiation >1600 kWh/m2-year a with a focus on the Mediterranean coast which falls into the Koppen-Geiger temperate climate classification Csa/Csb as evident in Figure 1.



Tropical	Arid (dry)	Temperate			Cold (continental)			Polar
Af	BWh	Csa	Cwa	Cfa	Dsa	Dwa	Dfa	ET
Am	BWk				Dsb	Dwb	Dfb	
Aw	BSh	Csb	Cwb	Cfb	Dsc	Dwc	Dfc	EF
As	BSk	Csc	Cwc	Cfc	Dsd	Dwd	Dfd	

Source: *Beck, Hylke E.; Zimmermann, Niklaus E.; McVicar, Tim R.; Vergopolan, Noemi; Berg, Alexis; Wood, Eric F. (30 October 2018). "Present and future Köppen-Geiger climate classification maps at 1-km resolution". Scientific Data.* ***5****: 180214. ISSN 2052-4463.*

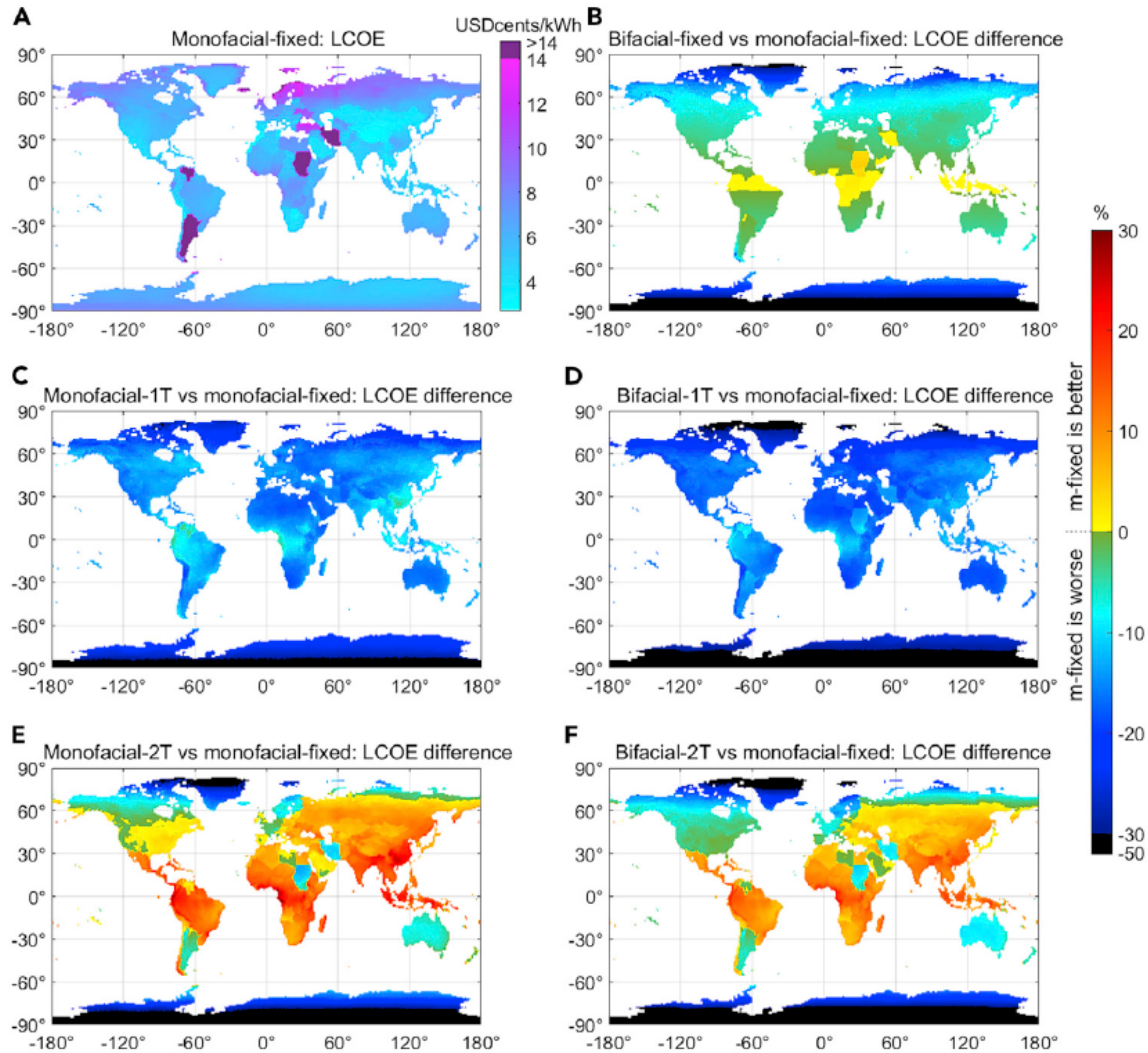
Figure 1. Koppen-Geiger Climate Classification

Tillman et al. (2020) calculate the energy yield and levelized cost of electricity generation (LCOE) for bifacial solar panel arrays at four locations with different climates. One of these locations is Seattle, Washington (WA), having a warm-temperate Mediterranean climate with relatively dry summers and cool wet winters, classified as Koppen–Geiger Csb. For this location, the LCOE reduction for bifacial modules with optimized tilt is found to reach 23.7% when compared with monofacial ones. The bifacial energy yield gain is found to reach 13.6%.

Rodríguez-Gallegos et al. (2020) present a worldwide analysis on the yield potential and cost effectiveness of solar PV farms composed of monofacial fixed-tilt and single/dual (1T/2T) tracker installations, as well as their bifacial counterparts, focusing on 10 locations across all continents. Their results reveal that bifacial-1T installations increase energy yield by 35% and reach the lowest LCOE levels for the majority of the world (93.1% of the land area). The difference in LCOE of bifacial systems versus monofacial ones according to tracker options worldwide is depicted in Figure 2. It can be observed that in Turkey bifacial-fixed and bifacial-1T systems are pretty advantageous yielding about 10-20% lower LCOE.

Shoukry et al. (2016) have developed a simulation tool capable of modelling the annual energy yield of both stand-alone bifacial module installations with vertical and tracked systems for stand-alone and in-field installations in different geographical locations. It is found that a fixed bifacial module has a higher yield than a tracked monofacial module. Results show that bifaciality is more advantageous than simple tracking systems in sun-belt regions, with the benefits of bifaciality more prominent for higher ground albedo coefficients. Simulations show, that vertically mounted bifacial modules can achieve a higher annual energy yield than south-facing monofacial modules in locations at higher latitudes. One of the simulation results shows that, while a stand-alone module with an optimum configuration yields a 33.9 % bifacial gain, the bifacial gain of the same module is decreased to 31.4 % in a field installation for the best and 27.7 % for the worst performing modules. Furthermore, simulations show, that vertically mounted bifacial modules can achieve a higher annual energy yield than south-facing monofacial modules in locations at higher latitudes.

The prediction accuracy of simulation results for bifacial technology is studied by Nussbaumer et al. (2020) comparing the results of various simulation tools with measured data under varying irradiation conditions and tilt angles. The deviations are found to be smaller than ±2% for 30° to 45° tilt angles and mostly well below ±1%. It is concluded that the observed trends in bifacial gains and the measured total electrical output are well predicted by all models, showing that bifacial yield modeling is reaching a stage of maturity.

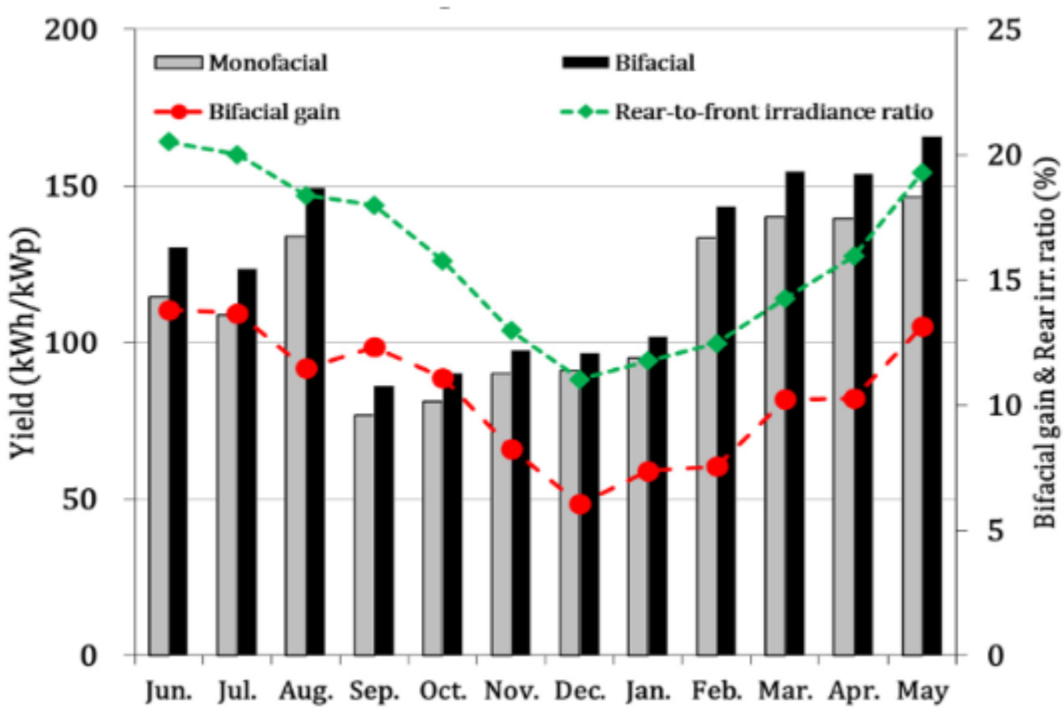


Source: *Rodríguez-Gallegos' C.D., Liu, H., Gandhi, O., Singh, J.P., Krishnamurthy, V., Kumar, A., Stein, J.S., Wang, S., Li, L., Reindl, T., Peters, I.M., 2020. Global Techno-Economic Performance of Bifacial and Tracking Photovoltaic Systems, Joule, Article In Press.*

Figure 2. Worldwide LCOE Results

(A) Estimated LCOE worldwide for monofacial fixed-tilt (m-fixed) installations.
(B–F) The following plots present the percentage difference between the LCOE (with respect to monofacial fixed-tilt) for (B) bifacial-fixed, (C) monofacial-1T, (D) bifacial-1T, (E) monofacial-2T, and (F) bifacial-2T.

Park et al. (2019) evaluate the outdoor performance of bifacial PV modules and string systems under different ground reflection conditions. The monthly average bifacial gain is found to vary from 6.1% (December) to 13.8% (June) under 21% ground reflection. For the module with 79% ground reflection, the gain is found to vary from 26.0% (February) to 45.1% (August) as shown in Figure 3. The tracker gain is found to change significantly from−12.7% (January) to 31.5% (May and June).



Source: Park, H., Chang, S., Park, S., Kim, W.K., 2019. Outdoor Performance Test of Bifacial n-Type Silicon Photovoltaic Modules, Sustainability, 11, 6234.

Figure 3. Monthly power yield (left) of monofacial and bifacial PV string systems and the resulting bifacial gains

Panel efficiency is determined by the cell layout, configuration and panel size, in combination with cell efficiency. As for the bifacial gain from total panel efficiency, a range of 7.9-16.8% is identified from 4-year measurements for GTC bifacial modules depending on monthly yield as shown in Figure 4.

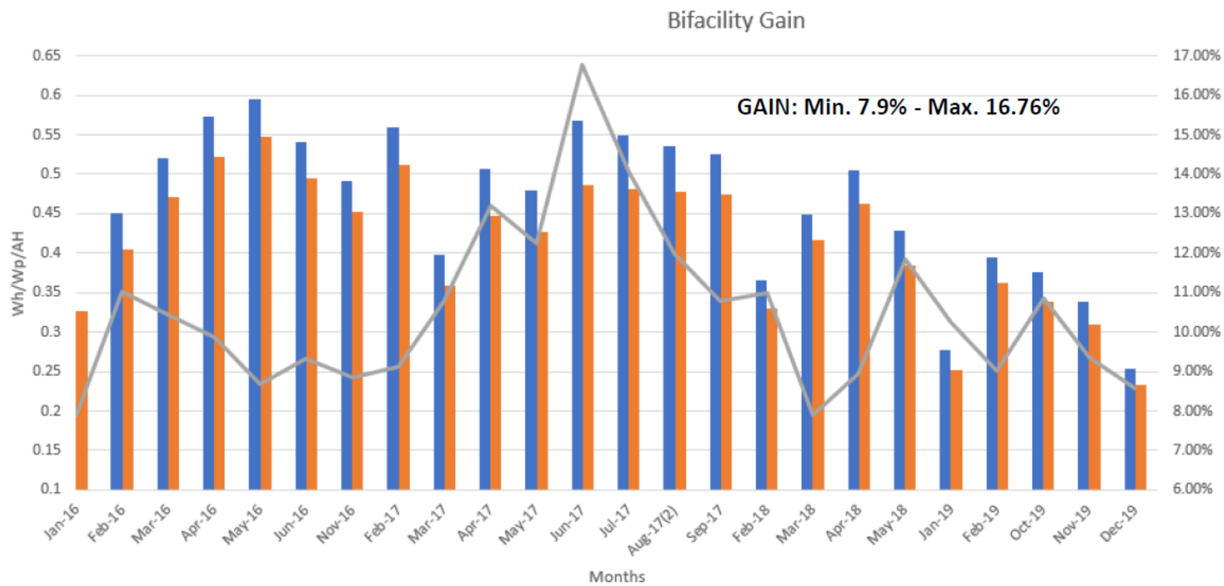


Figure 4. Monthly power yield (left) of monofacial and bifacial PV string systems and the resulting bifacial gains for GTC/Bostan

When Park et. al.'s (2019) results are compared with the performance of GTC bifacial panels, it is seen that the GTC bifacial gain is higher both in minimum and maximum values.

Libal/Kopecek (2019) claim that just like solar trackers a few years back, bifaciality will enter the US PV market with a high impact from 2020 on when the financing sector will have gained more confidence. For different system configurations and ground reflection conditions, the bifacial energy gain is observed. The smallest value observed is above 10% except of an outlier, and reaches 25-30% under different bifaciality values. Their cost computations, assuming a system lifetime of 25 years, a 6% discount rate and 16% tracking gain, show that the LCOE of bifacial systems are around 20% lower than for standard monofacial fixed tilt.

2. Technical Properties

2.1 Certification

The PV modules were tested by the A2LA accredited RETC Lab and certified by TÜV Intercert Certification Body based in Saarland, Germany, to comply with the safety and design qualification requirements set out in the certification program. TÜV certified type approval of the crystalline silicon terrestrial PV modules is based on voluntary product test with factory inspection. Test results verify the quality compliance of GTC modules with IEC (International Electrotechnical Commission) standards as certified by TÜV Intercert GmbH, group of TÜV Saarland Germany, accredited by the German accreditation body DAkks. The compliance with IEC 61215, which lays down requirements for the design qualification and type approval of terrestrial PV modules suitable for long-term operation in general open-air climates, is approved with the certification. The IEC is the world's leading organization headquartered in Switzerland, which prepares and publishes International Standards for all electrical, electronic and related technologies.

Technical and lifetime characteristics were verified by the Renewable Energy Test Center (RETC) based in Fremont CA, USA. The Extended Chamber Test composed of Wet Leakage Current, Wet Insultaion, Damp Heat, Electroluminescence and Maximum Power Determination tests were performed. The maximum power levels are identified depending on module type at a 95% confidence level, classifying the GTC modules as class A under standard laboratory procedures and per the international standards. The GTC insulation test after bypass diode thermal test results in a measurement of 2106 MΩ whereas the requirement is only 24.24 MΩ. Similarly the insulation tests after UV preconditioning, humidity freeze 10, robustness of terminations, thermal cycling 200, damp heat 1000, mechanical load and hail impact measure 2105 MΩ, 1702 MΩ, 1904 MΩ, 2285 MΩ, 1702 MΩ, 1509 MΩ and 1455 MΩ respectively, significantly outperforming the requirement of 24.24 MΩ. The visual inspection results are such that none of the tests shows a major visual defect. This result qualifies GTC panel as a potential top performer in all floating system and heavy weather projects.

Based on the results from the wet leakage current test, bypass diode thermal test, hot-spot endurance test, UV preconditioning test, humidity freeze 10 test, thermal cycling 200 test, damp heat 1000 test and hail impact test, GTC modules have passed well below limits maximum power deterioration, insulation test and visual criteria.

2.2 Durability Testing & Ageing

Finely tuned accelerated testing is the key to minimizing the occurrence of module failures in PV systems, and distinguishing between high-risk and low-risk products. Since the 1970's, accelerated tests for PV module reliability have been developed by applying stresses in a manner that reproduces observed failures of fielded modules in a laboratory test of reasonable duration. The accelerated tests in IEC 61215 are widely used and have been developed over the years to screen for module failures (Repins et al., 2020).

IEC 61215 is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules. The objective of the test sequence is to determine the electrical and thermal characteristics of the module and to show that the module is capable of withstanding prolonged exposure in general open-air climates.

In the IEC 61215 tests done by RETC, it is seen that the GTC modules excel in all tests providing satisfactory results and outperforming the requirements.

As GTC panels aged max 14% in 6000 hr Damp Heat IEC tests, this actually indicates that panels should perform at min 86% in 30 years. Peike et al.'s (2014) results provide a scientific reference in comparing the degradation mechanisms induced by outdoor exposure and by accelerated aging tests. The results are based on aging tests for up to 4000h, and seven different module types that were exposed outdoors in four different climates for up to three years. It is found that aging is highly dependent on the exposition site as a result of differences in irradiation, temperature and humidity. Highest intensity values were reached after aging in an arid and a tropic climate, followed by the mountain and the moderate climate.

GTC panels aged max 8.78% in 60 cycles of Humidity Freeze IEC tests and max 8.35% in 1200 cycle Thermal Cycle IEC tests. These low percentages attained in Durability tests done at accredited laboratories support the GTC official guarantee statement of 84% in 30 years.

The testing reports validate assumptions on technical characteristics like degradation, efficiency and lifetime that are used in the economic analysis as presented in the following section.

2.3 Safety Testing for Fire

The IAS accredited testing laboratory by Western Fire Center based in Kelso WA, USA, verified the panels to be Class A in both spread of flame and burning brand. For the Class A Spread of Flame Test a luminous gas flame is applied to the deck at a temperature of 1400 ± 50°F (760 ± 28°C) for a duration of 10 minutes. GTC modules passed the test with no ignition For the Class A Burning Brand Test, the Class A brand is ignited on a gas burner for 5 minutes, and then placed on the module approximately 38 cm from the leading edge with a 19.3 km per hour wind passing over it. The test continued until the brand was totally consumed and until all evidence of flaming, glowing and smoke disappeared from both the exposed surface of the material being tested and underside of the test deck or until failure occurred. The modules successful passed the test as only the top glass cracked and slight pop of module was observed within a 16-hour period. All in all, test results indicate the GTC solar modules' extremely strong durability against fire.

Various qualitative characteristics that do not influence the economic analysis like spread of flame and burning brand as identified from the fire testing results are included in the SWOT analysis that is presented in the final section of this report.

However this fire protection characteristics are extremely important in enabling factory rooftops and residential rooftops to install solar plants with maximum safety standards, as recent rooftop fire incidents in Turkey have shown. In May 2020, for example, the solar PV panel installed rooftop of a cattle farm in Bursa caught fire (Milliyet, 2020).

Solar panels catching fire has been a worldwide concern as incidents happened and triggered lawsuits. In August 2019, for example, lawsuits against Tesla solar panels started when Tesla -installed panels caught fire on a Walmart store rooftop in the United States (Bloomberg, 2019).

As pointed out by Kır et al. (2019), compliance with national and international standards needs to be taken seriously as a measure to prevent electrical fires.

3. Economic Analysis

3.1. Assumptions

The economic analysis is based on projected data for a solar farm with 35 MWe installed capacity using bifacial double glass GTC Mono-PERC solar panels. A comparison has been performed with monofacial Mono-PERC solar panels at the same installed capacity level, with two alternatives depending on whether domestically produced or imported. In the economic analysis, projectedl data is used together with the assumptions depicted in Table 1

Table 1. Assumptions used in the economic analysis

Here is a table with feasibilty analysis for 3 scenarios on a licensed solar plant;

- **In the first scenario;** the investor buys localy made standard 390W Mono Perc panels at the cheapest price available collecting 0.7 cent per kwh incentive from the government.
- **In the second scenario;** the investor buys imported standard 420W Mono Perc panel assuming there is no import tax.
- **In the third scenario;** the investor buys GTC bifacial 390W (front side) panels which are also localy made , hence collecting 0.7 cent per kwh incentive from the government.

	Option 1	Option 2	Option 3
	Monofacial Mono-PERC Standard Frame **(Local) / 390W**	**Monofacial** Mono-PERC Standard Frame **(Imported) / 420W**	**GTC Bifacial** Mono-PERC Double Glass **Local / 385W**
General Assumptions			
Panel Area (m2)	256,446 m2	237,870 m2	262,081 m2
Panel Quantity	128,223	118,935	129,870
Panel Capacity (W)	390 W	420 W	385 W
Peak Capacity (kWp)	50,007 kWp	49,953 kWp	50,000 kWp
Electric Capacity (kWe)	35,000 kWe	35,000 kWe	35,000 kWe
DC Unit Cost ($ / Wp)	$0.130	$0.130	$0.127
AC Unit Cost ($ / We)	$0.154	$0.154	$0.154
Panel Unit Cost ($ / Wp)	$0.250	$0.220	$0.295
EPC Cost ($)	$24,392,649	$22,873,445	$26,489,979
Project Development Cost ($)	$0	$0	$0
Total Investment Cost ($)	$24,392,649	$22,873,445	$26,489,979
Real Discount Rate (% / year)	5%	5%	5%
Project Life (years)	25	25	25
Generation			
Annual Generation (kWh / kWp / year)	1962	1979	2105
First Year Generation (kWh)	98,113,675	98,856,393	105,249,895
Degredation (% / year)	0.70%	0.70%	0.40%
Operational Cost			
Maintenance & Repair ($ / MW / year)	$9,000	$9,000	$7,000
Maintenance & Repair Cost ($ / year)	$315,000	$315,000	$245,000
Salary - Net (TL / employee / month)	2,020 TRY	2,020 TRY	2,020 TRY
Number of Employees	9	9	9
Salary Payments - Net (TL / month)	18,180 TRY	18,180 TRY	18,180 TRY
Gross Multiplier	1.75	1.75	1.75
Salary Payments - Gross (TL / month)	31,815 TRY	31,815 TRY	31,815 TRY
Annual Salay Increase	10%	10%	10%
Insurance ($ / MW / year)	$3,000	$3,000	$3,000
Risk Margin (% of Revenue)	1.0%	1.0%	1.0%

Table 1 cont'd

	Option 1	Option 2	Option 3
	Monofacial Mono-PERC Standard Frame **(Local) / 390W**	**Monofacial** Mono-PERC Standard Frame **(Imported) / 420W**	**GTC Bifacial** Mono-PERC Double Glass **Local / 385W**
Electricity Prices ($/MWh)			
Year 1-5	$0.1446	$0.1374	$0.1446
Year 6-10	$0.1330	$0.1330	$0.1330
Year 11-25	Monte Carlo	Monte Carlo	Monte Carlo
TEIAS Contribution Margin (TL)			
TEIAS Margin (TL Total; equally distributed over initial 3 years)	30,301,440 TRY	30,301,440 TRY	30,301,440 TRY
Distribution Fee (TL / kWh)			
Distribution Fee (TL / kWh)	0.0146 TRY	0.0146 TRY	0.0146 TRY
Price Increase (% / year)	10%	10%	10%
Exchange Rate (USD / TL)			
Exchange Rate (USD / TL)	6.75	6.75	6.75
Devaluation of TL (% / year)	10%	10%	10%
Tax			
Corporate Tax Rate	22%	22%	22%

3.2. Electricity Prices – Monte Carlo Simulation

The feed-in-tariff for solar power under the Renewable Energy Support Scheme (YEKDEM) is used in the calculations for the first 10 years of operation. The tariff for solar PV stands at $0.1330 per kWh, with a surplus for domestic manufacturing in the first 5 years. Accordingly, the electricity price for the first 10 years of operation is taken as follows:

Year 1-5 : $0.1446 per kWh

Year 6-10 : $0.1330 per kWh

Beyond year 10, the produced electricity will have to be sold in the marketplace. A Monte Carlo simulation has been done to estimate prices from the 11th year on. The following procedure has been employed to estimate the simulation parameters:

- ✓ Daily market clearing prices for the last 10 year (Dec.1, 2011 – July 1, 2020) are retrieved
- ✓ Annual and monthly average prices are computed
- ✓ The minimum extreme distribution and logarithmic distribution are identified as the best fits for annual and monthly prices respectively
- ✓ 10,000 Monte Carlo simulation runs are done

Results of the Monte Carlo simulation are depicted in Figure 5, together with historical data.

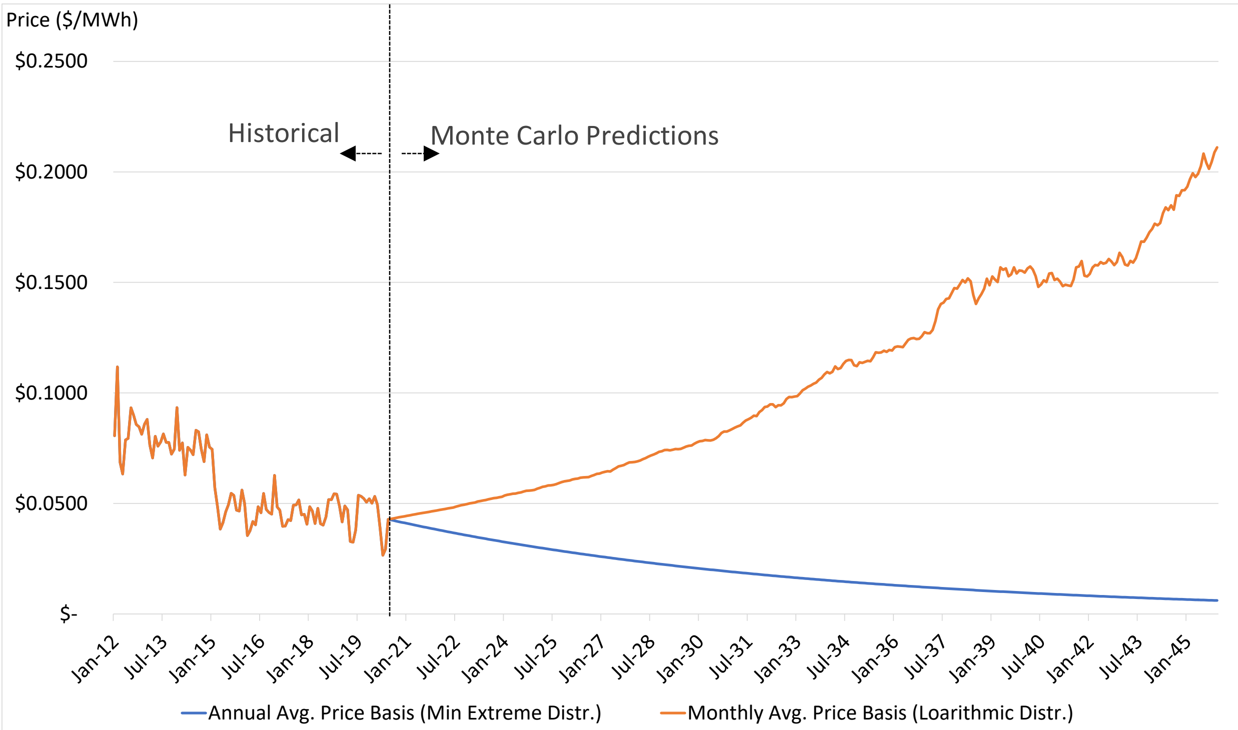


Figure 5. Electricity Price: Monte Carlo Simulations based on Monthly and Annual Average Prices

The average annual prices as a result of the 10,000 simulations for a 25-year period are shown in Table2 for the two scenarios based on (i) annual average prices with best fit minimum extreme distribution yielding a decreasing price trend and (ii) monthly average prices with best fit logarithmic distribution yielding an increasing price trend. The forecast for year 11, which corresponds to the first year after the end of the guaranteed feed-in tariff, is $0.0179 per kWh under the decreasing price trend scenario and $0.0834 per kWh under the increasing price trend scenario. The long-term average growth rate of prices from the simulation result corresponds to roughly 6.4% per annum while the long-term decline rate corresponds to 8.2%. It should be noted that the prices are all nominal values. The real discount rate is taken as 5% (see Table 1) implying that the real price change margin is about 2%. This margin is taken as a basis in the sensitivity analysis in section 3.4 when evaluating the impact of price changes on the economic analysis. The wide spectrum provided by the two scenarios and the added sensitivity analysis provide a solid understanding of the impact of prices on the economic analysis. Nevertheless a third scenario assuming electricity prices to remain constant (at $0.0428 per kWh) is also included in the analysis.

Table 2. Electricity Price Forecast - Monte Carlo Simulation Results

Year	Decreasing Price Trend ($/MWh)	Increasing Price Trend ($/MWh)
1	0.0418	0.0394
2	0.0406	0.0487
3	0.0355	0.0516
4	0.0318	0.0547
5	0.0264	0.0577
6	0.0223	0.0613
7	0.0202	0.0650
8	0.0175	0.0691
9	0.0174	0.0732
10	0.0180	0.0786
11	0.0179	0.0834
12	0.0160	0.0906
13	0.0133	0.0987
14	0.0117	0.1090
15	0.0107	0.1111
16	0.0094	0.1390
17	0.0094	0.1382
18	0.0090	0.1477
19	0.0085	0.1542
20	0.0075	0.1528
21	0.0069	0.1522
22	0.0064	0.1586
23	0.0060	0.1646
24	0.0054	0.1839
25	0.0049	0.2023

3.3. Results

The payback period, IRR and NPV values computed for the options obtained under the presented assumptions are shown in Table 3.

Table 3. Economic Analysis Results

(a) Decreasing Price Trend

	Option 1	Option 2	Option 3
Simple Payback Period (years)	**2.37**	**2.34**	**2.36**
Discounted Payback Period (years)	**2.42**	**2.39**	**2.40**
IRR	**40.80%**	**41.80%**	**41.11%**
NPV	**$56,661,023**	**$56,311,774**	**$63,196,750**

(b) Increasing Price Trend

	Option 1	Option 2	Option 3
Simple Payback Period (years)	**2.37**	**2.34**	**2.36**
Discounted Payback Period (years)	**2.42**	**2.39**	**2.40**
IRR	**41.46%**	**42.45%**	**41.77%**
NPV	**$100,347,598**	**$100,329,055**	**$112,625,490**

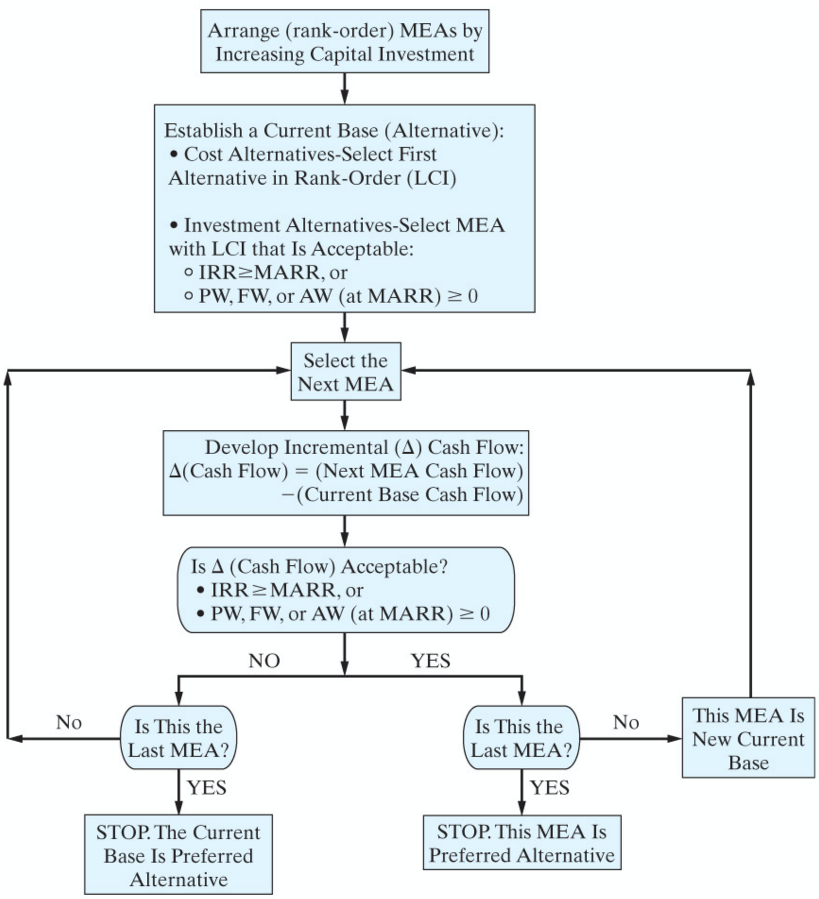
(c) Constant Price

	Option 1	Option 2	Option 3
Simple Payback Period (years)	**2.37**	**2.34**	**2.36**
Discounted Payback Period (years)	**2.42**	**2.39**	**2.40**
IRR	**40.88%**	**41.88%**	**41.19%**
NPV	**$63,963,289**	**$63,669,318**	**$71,475,006**

In all scenarios, the NPV of option 3 is highest when compared with option 1 &2, indicating the added value of the GTC bifacial modules. In terms of NPV, the GTC bifacial panels yield $112.6 million whereas $100.3 million is attained by monofacial systems under increasing electricity prices. Under decreasing prices the GTC bifacial panels yield $63.2 million whereas $56.7 million is attained by monofacial systems. When the electricity price is fixed, the GTC bifacial panels yield $71.5 million whereas $63.9 million is attained by monofacial systems. It is observed from the NPV values that an additional investment expenditure of $3.5 million generates $6.9 million, $12.3 million and $7.8 million additional net profit under the decreasing, increasing and constant price scenarios respectively.

The payback period does not change for the different price scenarios because the investment pays back in less than 3 years in all scenarios when the electricity produced is still sold under fixed prices determined by the Renewable Energy Support Scheme.

In terms of IRR, the values of the different options are not directly comparable. It should be noted that attempting to rank options similarly based on their IRR values would be a major mistake. Only incremental analysis is possible for project comparison of mutually exclusive investment alternatives based on rate of return methods. This is due to the assumption inherent in the IRR methodology where funds generated throughout the project are reinvested at the calculated rates of return rather than market rates. Therefore, the IRR values of mutually exclusive investment alternatives cannot be compared directly to identify the best option: an **incremental rate of return** analysis is needed. Incremental internal rate of return is the discount rate at which the present value of periodic differential cash flows of two projects equals the difference between the initial investments needed for each project. Hence, the incremental analysis starts with the least cost investment project and evaluates if the additional investment in a more expensive project is justified. The methodology employed in the incremental analysis is shown in Figure 6.



MEA: Mutually Exclusive Alternative
LCI: Least Capital Investment

Figure: 06-06

Figure 6. Incremental Rate of Return Methodology

Results of the incremental rate of return analysis for the three price scenarios are as follows:

a) Decreasing Price Trend Scenario

Option 1 vs Option 2: Incremental Cash Flow

Year	Cash Flow	Year	Cash Flow
0	(1,519,203.60)	13	(17,664.30)
1	524,816.04	14	(15,603.80)
2	516,043.33	15	(12,687.60)
3	507,795.57	16	(10,482.49)
4	500,026.95	17	(9,332.75)
5	492,695.81	18	(7,893.20)
6	(72,543.53)	19	(7,787.41)
7	(72,035.72)	20	(8,034.02)
8	(71,531.47)	21	(7,927.95)
9	(71,030.75)	22	(6,932.20)
10	(70,533.54)	23	(5,556.89)
11	(21,282.33)	24	(4,737.25)
12	(20,496.30)	25	(4,219.55)

The resulting **incremental rate of return is 16.81%**. Since the incremental rate of return is higher than the discount rate (5%), the incremental investment into Option 1 is justified. Hence we compare Option 3 to Option 1

Option 1 vs Option 3: Incremental Cash Flow

Year	Cash Flow	Year	Cash Flow
0	(2,097,330)	13	316,596
1	924,073	14	292,962
2	945,706	15	254,063
3	967,689	16	224,078
4	989,961	17	209,670
5	1,012,468	18	189,297
6	907,845	19	191,001
7	933,182	20	198,952
8	958,215	21	200,641
9	982,949	22	185,450
10	1,007,385	23	162,025
11	351,449	24	148,347
12	349,529	25	140,038

The resulting **incremental rate of return is 44.57%. %**. In other words, the incremental investment on the GTC bifacial panels brings an incremental return of 44.57% in addition to the locally produced monofacial panel.

b) Constant Price Trend Scenario

Option 1 vs Option 2: Incremental Cash Flow

Year	Cash Flow
0	(1,519,203.60)
1	524,816.04
2	516,043.33
3	507,795.57
4	500,026.95
5	492,695.81
6	(72,543.53)
7	(72,035.72)
8	(71,531.47)
9	(71,030.75)
10	(70,533.54)
11	(21,816.95)
12	(21,664.23)

Year	Cash Flow
13	(21,512.58)
14	(21,362.00)
15	(21,212.46)
16	(21,063.98)
17	(20,916.53)
18	(20,770.11)
19	(20,624.72)
20	(20,480.35)
21	(20,336.99)
22	(20,194.63)
23	(20,053.26)
24	(19,912.89)
25	(19,773.50)

The resulting **incremental rate of return is 16.52%**. Since the incremental rate of return is higher than the discount rate (5%), the incremental investment into Option 1 is justified. Hence we compare Option 3 to Option 1

Option 1 vs Option 3: Incremental Cash Flow

Year	Cash Flow
0	(2,097,330)
1	924,073
2	945,706
3	967,689
4	989,961
5	1,012,468
6	907,845
7	933,182
8	958,215
9	982,949
10	1,007,385
11	358,906
12	366,335

Year	Cash Flow
13	373,674
14	380,923
15	388,084
16	395,156
17	402,142
18	409,041
19	415,854
20	422,583
21	429,227
22	435,789
23	442,267
24	448,663
25	454,979

The resulting **incremental rate of return is 44.65%**. In other words, the incremental investment on the GTC bifacial panels brings an incremental return of 44.65% in addition to the locally produced monofacial panel.

c) Increasing Price Trend Scenario

Option 1 vs Option 2: Incremental Cash Flow

Year	Cash Flow
0	(1,519,203.60)
1	524,816.04
2	516,043.33
3	507,795.57
4	500,026.95
5	492,695.81
6	(72,543.53)
7	(72,035.72)
8	(71,531.47)
9	(71,030.75)
10	(70,533.54)
11	(19,999.24)
12	(24,796.42)

Year	Cash Flow
13	(26,151.62)
14	(27,591.32)
15	(28,957.61)
16	(30,613.12)
17	(32,295.28)
18	(34,155.99)
19	(35,989.06)
20	(38,447.22)
21	(40,570.20)
22	(43,849.25)
23	(47,522.66)
24	(52,216.02)
25	(52,868.05)

The resulting **incremental rate of return is 16.11%**. Since the incremental rate of return is higher than the discount rate (5%), the incremental investment into Option 1 is justified. Hence we compare Option 3 to Option 1

Option 1 vs Option 3: Incremental Cash Flow

Year	Cash Flow
0	(2,097,330)
1	924,073
2	945,706
3	967,689
4	989,961
5	1,012,468
6	907,845
7	933,182
8	958,215
9	982,949
10	1,007,385
11	333,553
12	411,406

Year	Cash Flow
13	442,480
14	476,082
15	509,846
16	549,544
17	591,207
18	637,470
19	684,970
20	745,405
21	801,943
22	882,287
23	973,302
24	1,087,922
25	1,125,085

The resulting **incremental rate of return is 44.74%**. In other words, the incremental investment on the GTC bifacial panels brings an incremental return of 44.74% in addition to the locally produced monofacial panel.

As can be seen from the results of the IRR analysis, the additional investment of the GTC bifacial panel yields significant additional income throughout the project lifetime in all of the price scenarios such that the incremental rate of return is at least 44%.

3.4. Sensitivity Analysis

A sensitivity analysis is carried out under different assumptions for discount rate, electricity prices and economic lifetime. The following ranges were used:

Discount Rate	: Base 5%; Sensitivity 3% and 7%
Electricity Prices	: Base Monte Carlo (MC); Sensitivity MC-2% and MC +2%
Economic Life	: Base 25 year; Sensitivity 30 years and 35 years

The sensitivity analysis is performed for the increasing price scenario only as findings will be the same for the constant and decreasing price scenarios. Results of the sensitivity analysis are summarized in Tables 4-6 where extraordinarily high and low values are color-coded with NPV< $90,000 highlighted in red and NPV> $140,000 highlighted in green. The color coding is done for ease of visual analysis to have a better understanding at first glance. The values $90k and $140k have no special meaning attached, are chosen at the occurrence of larger gaps so as to highlight the difference between the scenarios.

Table 4. Sensitivity Analysis Results for Monofacial -local

Electricity Prices	3% discount rate			5% discount rate			7% discount rate		
	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs
MC-2%	130,030,230	156,788,268	183,100,044	99,268,255	114,593,684	128,284,853	77,150,514	86,027,180	93,244,832
MC	131,591,003	158,916,472	185,783,477	100,347,598	115,998,033	129,978,121	77,907,005	86,971,926	94,341,894
MC+2%	133,151,776	161,044,675	188,466,910	101,426,941	117,402,381	131,671,389	78,663,496	87,916,672	95,438,956

Green: NPV> $140,000; Red: NPV< $90,000

Table 5. Sensitivity Analysis Results for Monofacial –imported

Electricity Prices	3% discount rate			5% discount rate			7% discount rate		
	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs
MC-2%	130,087,757	157,054,264	183,570,318	99,241,542	114,686,373	128,483,840	77,090,286	86,036,113	93,309,804
MC	131,660,345	159,198,578	186,274,065	100,329,055	116,101,353	130,189,926	77,852,503	86,988,011	94,415,171
MC+2%	133,232,932	161,342,892	188,977,811	101,416,569	117,516,332	131,896,011	78,614,721	87,939,908	95,520,537

Green: NPV> $140,000; Red: NPV< $90,000

Table 6. Sensitivity Analysis Results for Bifacial GTC

Electricity Prices	3% discount rate			5% discount rate			7% discount rate		
	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs	25 yrs	30 yrs	35 yrs
MC-2%	146,262,174	177,646,051	208,953,332	111,406,595	129,379,461	145,668,192	86,409,513	96,818,486	105,404,570
MC	148,026,581	180,070,812	212,034,047	112,625,490	130,976,541	147,606,565	87,262,942	97,890,949	106,656,940
MC+2%	149,790,988	181,835,219	215,114,763	113,844,385	132,195,436	149,544,938	88,116,371	98,744,377	107,909,309

Green: NPV> $140,000; Red: NPV< $90,000

It can be seen from the above tables that results are highly sensitive to the discount rate and lifetime, and less sensitive to prices. At the same discount rate and lifetime, GTC panels yield NPVs that are around 10% higher than others, which is even true when the electricity produced from bifacial GTC panels are sold at the lowerprice level (MC-2%) and others are sold at the higher one (MC+2%). From the color coding in the tables, it can be seen that the bifacial GTC panels yield high NPVs (> $140,000) even at 25-year lifetime which is not the case for others. From all the analyzed cases, the possibility of a relatively high NPV (> $140,000) is 6/27 for monfacial panels whereas it is 9/27 for bifacial GTC ones. The possibility of a relatively low NPV (< $90,000) is 6/27 for monfacial panels whereas it is 3/27 for bifacial GTC ones.

It should be noted that the GTC panel tests indicate an economic lifetime of 30 years rather than 25 (as has been assumed in the base calculations). Hence the calculations are rather conservative and hence there is more an upward margin rather than down for the bifacial GTC panels.

Having identified the sensitivity to discount rate and lifetime, the sensitivity graph in Figure 7 is constructed focusing on the most sensitive two factors. The impact of bifacial GTC panels, compared to monofacial ones at given discount rate and lifetime assumptions is evident. It should be noted that the two monofacial options (locally produced and imported) cannot be distinguished in the graph as the values are too close to each other (see Tables 4-6) and lines are overlapping. The bifacial panel makes the difference. It is further observed that sensitivity increases further as discount rate lowers, which can be identified from the steeper slope at lower discount rates.

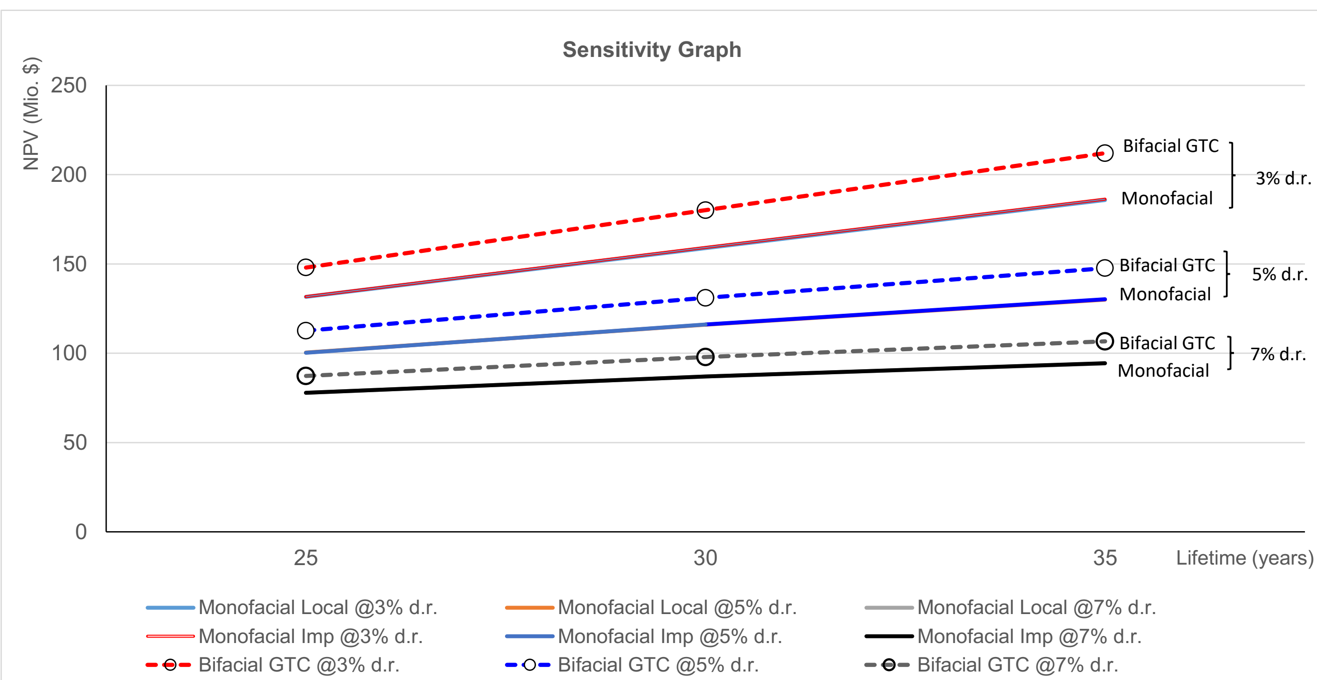


Figure 7. Sensitivity of NPV on Lifetime and Discount Rate

4. SWOT Analysis

STRENGTHS	WEAKNESSES
Patented technology for high efficiency electricity generation	Initial cumulative investment costs greater than monofacial standard panels for same front side DC
Panel does not weigh more than standard panels	Higher price per watt based on only front power
Single Turkish brand for bifacial production	Lesser front side DC load meaning less total markup for EPC's in bifacial solar plants
Electricity generation amount higher than monofacial Mono-PERC for equal front side DC load	Requires skilled EPC installation crews to comply with higher quality requirements of handling glass glass modules
High-quality product with very high resistance levels in compliance with IEC standards	New technology with relatively rare execution locally, unknown with a low profile
Longer lifetime than monofacial Mono-PERC	Lower brand recognition, "no name product"
Reduced maintenance cost due to glass-glass frameless design	Being local and not part of a Tier1 foreign company causes disregard and distrust by local banks and investors
Class A burning brand and Class A spread of flame extremely strong durability against fire	Needs a high marketing budget to win broader customer support and recognition
Provides an insulation sheet against electrical fires	
High durability (low ageing) results under IEC 61215 TC1200, HF60, DH6000 extended tests	
Lower LCOE compared to monofacial standard panels under all conditions	
Excellent electricity production boost when used with trackers	
Generates equal electricity on fixed mount as monofacial standard panels on trackers	
Minimum 6% gain on white rooftop installations	
Locally Produced	
Locally Designed	
Direct Contributor to local skilled employment	
A Research and Development Powerhouse in Solar	
PVC free Green Product	
Low metal content Green Product	
Low carbon foot print	

Locally Engineered	
OPPORTUNITIES	**THREATS**
More electricity production on same square area of Panels/Roofs/Fields	Potential for other competitors to produce similar products
60 cell Panels including mounting apparatus on a rooftop weigh less than standard panels	Loss of YEKDEM price incentives for future investments
Lower LCOE may be even lower with R&D induced gains in technology	Removal of barriers for imported state subsidized far eastern solar panels
Presently a new brand & technology in Turkey, should be developed with right marketing tools	Non-analytical Investors & Consumers who feel comfortable copying and following the status quo
Big opportunity in BIPV markets as glass thicknesses and sizes can be adjusted in production for custom tailoring	Market Misinformation Complacent Solar Consultants
YEKA and other governmental tenders may require locally made cells and panels depending on governmental policy	Believers of Fate Uneducation regarding international guarantees
Private sector PV investments/movements may require more quality & safety as bad examples arise in the sector	Trade advantages within Turkey given to Free Trade Zone international producers by the Turkish government
Solar may develop into a long term investment strategy like all other energy investments requiring longer life times for solar panels	International Tier1 players moving into Turkey through their local agents selling their know-how forcing local companies lose market share
Equal investment cost per electricity produced 1st year in solar plants where the plants are designed to have less DC load than standard plants resulting in equal electricity output- all succeeding years LCOE cost per electricity produced becomes actually lower as GTC panels age slower comparatively producing more electricity across time	Government disregard and lack of a comprehensive support program for Turkish made technology and innovation in local industrial production

Based on the above technical, financial and SWOT analysis and study of both Bifacial panels and GTC products, it is our conclusion that bifacial panels perform better in comparison to Monofacial panels in multiple ways and that it would be a correct conclusion to consider GTC Bifacial panels highly competitive for YEKA, YEKDEM and Roof investments.

5. References:

Bloomberg, 2019. “Tesla Solar Panels Catch Fire, and the Lawsuits Start Flying”, Business Article by Dana Hull and Brian Eckhouse published on 29 August 2019. Available online: https://www.bloomberg.com/news/articles/2019-08-29/more-tesla-solar-panel-cases-emerge-in-wake-of-walmart-suit

ITRPV, 2020. International Technology Roadmap for Photovoltaic, 11th Edition April 2020.

Kır, F, Özdemir, N, Topgaç Y.S., 2019. “Elektrik Kaynaklı Yangınlar ve Korunma Yöntemleri”, Article available online: http://www.emo.org.tr/ekler/0a360f25b58644e_ek.pdf

Libal, J. and Kopecek, R., 2019. Bifacial Photovoltaics: Technology, Applications and Economics: Technology, Applications and Economics, The Institution of Engineering and Technology.

Milliyet, 2020. “Bursa'da içinde hayvanların bulunduğu çiftlik yandı”, Daily newspaper article published on 29 May 2020. Available online: https://www.milliyet.com.tr/gundem/son-dakika-bursada-icinde-hayvanlarin-bulundugu-ciftlik-yandi-6222326

Nussbaumer, H., Janssen, G., Berrian, D., Wittmer, B., Klenk, M., Baumann, T., Baumgartner, F., Morf, M., Burgers, A., Libal, J., Mermoud, A., 2020. Accuracy of simulated data for bifacial systems with varying tilt angles and share of diffuse radiation, Solar Energy, 197, 6-21.

Park, H., Chang, S., Park, S., Kim, W.K., 2019. Outdoor Performance Test of Bifacial n-Type Silicon Photovoltaic Modules, Sustainability, 11, 6234.

Peike, C., Hoffmann, S., Dürr, I., Weiß, K.-A., Bogdanski, N., Köhl, M., 2014. “PV module degradation in the field and in the lab - how does it fit together?”, Paper presented at the 29th European PV Solar Energy Conference and Exhibition. Available online: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/conference-paper/29-eupvsec-2014/Peike_5BV41.pdf

Repins, I.L., F.Kersten, B.Hallam, K.VanSant,,M.B.Koentopp, 2020. Stabilization of light-induced effects in Si modules for IEC 61215 design qualification, Solar Energy, 208, 894-904.

Rodríguez-Gallegos’ C.D., Liu, H., Gandhi, O., Singh, J.P., Krishnamurthy, V., Kumar, A., Stein, J.S., Wang, S., Li, L., Reindl, T., Peters, I.M., 2020. Global Techno-Economic Performance of Bifacial and Tracking Photovoltaic Systems, Joule, Article In Press.

Shoukry, I., Libal, J., Kopecek, R., Wefringhaus, E., Werner, J., 2016. Modelling of bifacial gain for stand-alone and in-field installed bifacial PV modules, Energy Procedia, 92, 600-608.

Tilmann, P., Jäger, K., Becker, C., 2020. Minimizing the levelized cost of electricity for bifacial solar panel arrays using Bayesian optimization, Sustainable Energy and Fuels, 4, 254-264.