**POWER CELL**
**Ministry of Power, Energy and Mineral Resources**
**Government of People's Republic of Bangladesh**

# FINAL REPORT

**ON**

# FEASIBILITY STUDY FOR MULTIPURPOSE USE OF LAND FOR RENEWABLE ENERGY PROJECT IN BANGLADESH


**Submitted by**

**STEAG Energy Services India Pvt. Ltd.**
**in association with**
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# EXECUTIVE SUMMARY

## BACKGROUND

Bangladesh being an agrarian and a densely populated country that is dependent on agriculture and related activities, the availability of land for other purposes becomes a challenge. Considering this land crunch, it would be prudent and the need of hour to co-locate the land extensive RE based power plants that is used not only for power generation but also for farming to sustain the economy of the country. With this background GoB is examining the option of multiple use of land for electricity generation through renewable sources.

With the above background, this report explores various aspects of Multipurpose use of land along with Agricultural farms, Fish farms and animal farms.

## BASIC CRITERIA OF MULTIPURPOSE USE

**Multipurpose use of RE with Agricultural farms**

The multipurpose use of RE with agricultural farms depends upon the following main criteria:

- The RE resource availability in that area
- The shade tolerance of the crops

As far as RE (primarily solar) resource is concerned, more than half of Bangladesh receives more than 1700 kWh/m2 of GHI on an annual basis. The Chittagong Zone and the Southern coastal regions of Khulna and Barisal Zones are particularly good.The middle part of the country is moderate in terms of Irradiation received while the upper regions are not so promising.

The second important criteria i.e. the shade tolerance of the crops in Bangladesh is as follows:

**Table 0-1: Shade tolerance level of various crops**

| Deep shade tolerance crops (up to 60%) | Moderate shade tolerance crops (up to 40%) | Lower shade tolerance crops (up to 20%) |
|---|---|---|
| Betel leaf, Taro | Vegetables- (Tomato, Carrot, Potato, Eggplant Pumpkin, Beets, Spinach, Broccoli, Lettuce, Radish, Cabbage and Cauliflower) and Spices- (Chili, Turmeric, Zinger,, Garlic; Fruits: Banana; Oil seeds: Pea nut, ground nut. | Cereals: Aus rice, Aman rice (Aromatic rice), Pulses (black gram, mash, moong and pigeon pea. |

Out of the above, the 40% shade tolerant crops are most promising (60% category being the minor crops and 20% tolerance being too low to be considered) and have been considered for calculations and analysis in this report. The total area in Bangladesh with these crops is around 12.68 Lakh acres.

**Multipurpose use of RE with Fisheries**

The water bodies considered for multipurpose use are the still water bodies and out the various types of still water bodies, the commercial fish farms (Intensive and highly intensive category) are found to be the most promising for multipurpose use. The commercial fish pond area in different divisions of Bangladesh is given in the table below which is also categorized as per the type of fish farming.

**Table 0-2: Pond area for fish varieties in Bangladesh – Division wise**

| S. No. | Division | Extensive (<1.5 MT/Ha) | Semi-intensive (1.5 – 4.0 MT/Ha) | Intensive >4-10 MT/Ha | Highly intensive >10.0 MT/Ha | Total (Ha) |
|---|---|---|---|---|---|---|
| 1. | Dhaka | 2133 | 25712 | 15578 | 1688 | 45111 |
| 2. | Mymensingh | 1181 | 16403 | 16623 | 10726 | 44933 |
| 3. | Khulna | 9570 | 31426 | 13835 | 2583 | 57414 |
| 4. | Barishal | 2656 | 23342 | 6319 | 40 | 32357 |
| 5. | Rangpur | 452 | 29640 | 11313 | 640 | 42045 |
| 6. | Rajshahi | 515 | 45959 | 23674 | 1336 | 71484 |
| 7. | Chattogram | 10350 | 60140 | 18264 | 1266 | 90020 |
| 8. | Sylhet | 5749 | 11028 | 4223 | 133 | 21133 |
| | Total | 32606 | 243650 | 109829 | 18412 | 404497 |

Reference: Department of Fisheries (DoF), 2021. Yearbook of fisheries statistics of Bangladesh, 2019-2020. Department of Fisheries, Bangladesh

Atypical commercial fish pond size in Bangladesh is around 70 to 100 ft long, 35 to 50 ft wide and 4-5 ft water deep. This small size means that the individual ponds are not good enough and the places good for multipurpose use of these ponds for solar installations would be the ones where there are a number of ponds in clusters or close vicinity.

The large water bodies (Extensive and Semi intensive categories) that may be having enough area to have individual plantsinclude wetlands, beels and lakes. While in such large water bodies, floating solar is always possible but because of the large area, it will be possible to find separate areas for fishing and separate place for installing solar. It will therefore not come under the multipurpose use and rather come under floating solar.

**Multipurpose use of RE with Animal Husbandry**

For the animal husbandry, the possibility of solar installation is both at the shed area of the animals as well as the grass production area.

The shed area (total about 27,000 acres) is very small as compared to the suitable grass production areas which are about 9 lakh acres. The sheds have a number of limitations for being used as a part of grid connected plant. They are too small and too scattered to become even a part of a grid connected facility. Moreover, they may require strengthening for installation of solar panels. Therefore, they will not significantly contribute to multipurpose use effort.

The grass production areas on the other hand will definitely contribute to multipurpose use of land as these are large contiguous areas and can be treated similar to multipurpose use of land for RE with agricultural fields.

## DESIGN CONSIDERATIONS IN MULTIPURPOSE USE

- In view of the food security of the country, the Agriculture centric approach is to be adopted while going for multipurpose use.

- It is to be ensured that the yield of the basic trade (agriculture / fisheries / animal husbandry) is not reduced by more than 10%.
- The Land equivalent ratio must be more than 1.5.
- The ground clearance of the panels for agrivoltaics is to be kept minimum 3.5 m for mechanized farming and 1.5m for manual farming.
- In view of the high structures, it is preferable to use robotic cleaning with a walkway on one side.
- In view of the high structures, the structure needs to be strengthened to counter the wind load.
- The inter row distance is to be increased to limit the shading.
- In view of the above point, the string inverters are preferable to limit the DC losses.
- Tracking mechanism should be deployed to ensure homogeneity of light on the crops.

## PLANT DESIGN

**Plant design for Agrivoltaics**

The main consideration of design of PV plants in the agricultural fields is to keep the total loss of yield in crops because of multipurpose use to less than 10%. Since, 40% shade tolerant crops are being considered, therefore the area of fields that is shaded more than 40% is to be kept below 10%, after the installation of PV plants. The area that would be shaded by different elements in a solar plant would depend upon the following parameters:

- Configuration of panels – 1Portrait, 2 Portriat, 2 Landscape, 4 landscape etc.
- Pitch of the panel rows – Corresponding to different ground coverage ratios. More is the pitch, more is the light reaching the ground
- Panel Tilt – Starting from flat panels to Latitute of the site
- Height of the panels – Higher the panel, more would be the light reaching the ground from below the panels
- Azimuth – Tilt of the panel to the South
- Fixed tilt / Tracker –Tracker is likely to give more homogeneity of light

Variation of the above parameters gives several permutations and combinations and each set gives a different figure of percentage land area that has shade of less than 40%. To compute this area of less than 40% shading arising out of various permutations and combinations of the above parameters, simulation exercises were run.

The base case for the simulation exercise comprises of the following parameter set and the area under 40% shading was found to be 63.3%

**Table 0-3: Base case parameters considered for simulation exercise**

| Particulars | Base Case |
|---|---|
| Configuration | 1P |
| Pitch (m) | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% |
| Panel Tilt (Degrees) | 15 |
| Height (m) | 3.75 |
| Azimuth (Degree) | 180 |

More than 30 cases were simulated and analyses out of which 12 important ones have been presented in this report. Out of these the best case is the following

**Table 0-4: Results of Simulation Analyses**

| Particulars | Base | Best Case |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | Tracker |
| Height (m) | 3.75 | 5 |
| Azimuth (Degree) | 180 | 180 |

For the above case, the yield loss of agriculture is below 10%. It is therefore the recommended design for multipurpose use of land for RE with Agricultural and grass fields.

**Plant design for multipurpose use with Fish ponds (Aquavoltaics)**

In case of the fish ponds, at least half of the area on the longer side of the pond is to be kept free of panels to facilitate the fish harvesting. Also, the sides of the pond should have some vacant area. The reason for this is that the ponds' depth keeps varying in the rainy and dry season. The areas along the banks have to be left without solar panels as they are likely to get shaded by the banks when the water level goes down in the dry season. This area to be kept vacant on each side of the pond should be around 1.5 times the depth of the water from the ground (maximum depth that comes in the dry season).

With the above configuration, about 40% of the pond area can be used for putting solar.

## BUSINESS MODELS AND THEIR FINANCIAL ANALYSIS

There are three business models that have been considered for financial analysis of multipurpose use. The first business model pertains to a solar development company that proposes to develop a solar farm by taking land on lease from person(s) involved in any of the basic trades i.e. Agriculture or Fish farming or Animal husbandry.

This second business model pertains to an established basic trade company (Agriculture or Fish farming or Animal husbandry) that proposes to add Solar power generation into its existing business.

The third business model pertains to a solar development company who proposes to develop a new Solar farm that will have a multipurpose use with any of the basic trades i.e. Agriculture or Fish farming or Animal husbandry.

**Assumptions and Analysis for Multipurpose use of RE with agricultural fields**

For this analysis, four scenarios have been considered. The first is the base case in which a solar Company is doing only Solar business (No multipurpose use) on a standard ground mounted and grid connected system. This Base case gives a certain project IRR and Equity IRR. Further, the financial model is run for the three Business models as described above. The methodology to arrive at a suitable tariff for any business model is to first change the assumptions in the base case as per the particular and then tweak the tariff till the time the business model gives the same IRR as the base case.

**Table 0-5: – Assumptions for base case in multipurpose use of land with Agricultural fields**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1$^{st}$ year<br>0.8% per year from 2$^{nd}$ to 20$^{th}$ year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 10,00,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWp |

Tariff for Business model 1 comes out to be the same as the base case. The reason is that in this business model (as compared to the base case) the land required per MWp of Solar as well as Capex are increasing, which increase the Tariff. But the generation is also increasing as compared to the base case which is balancing this increase and hence the computed Tariff shall be the same as the base case to achieve similar IRR as the base case.

Tariff for Business model 2 also comes out to be the same as the base case. As explained earlier, this model pertains to an established agricultural company getting into Solar power generation. The company would setup a subsidiary company for solar project development to whom it would lease the land. The basic structure is the same as in model 1, the only difference is that a solar development company in this case is leasing land from its own parent company rather than other farmers as in model 1. The dynamics of this model are similar to model 1 and hence the computed tariff is also the same.

For Business model 3, the tariff comes out to be 0.128 USD Cents / kWh as compared to 0.11USD Cents / kWh in the base case. The reason for this is that the solar is a high margin business as compared to agriculture and hence utilizing their land for agriculture reduces the IRR for the overall business and hence a higher tariff would be required to get an IRR equal to the base case. It is also possible that the solar development company setups an agricultural subsidiary and leases land to it for doing agriculture. In that case the dynamics will become similar to the first two models and extra tariff can be avoided but practically Solar development companies will have limited interest in such a proposition.

**Assumptions and Analysis for Multipurpose use of RE with Fish farms**

The methodology for model development and calculation of proposed tariff for commercial fish farms that are being considered for the multipurpose use with RE, is same as the methodology as explained above for the multipurpose use of Agricultural farms.

**Table 0-6: – Assumptions for base casein multipurpose use of land with fish farms**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1st year<br>0.8% per year from 2nd to 20th year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 100,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |

| Particulars | Assumptions |
|---|---|
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWp |

For Business model 1 and 2 the tariff comes out to be 0.131 USD Cents / kWh as compared to 0.11 USD Cents / kWh in the base case. The reason is that in the business model 1, the land required per MW of Solar as well as Capex (as compared to the base case) are increasing that increase the Tariff. However, unlike the case of Agrivoltaics (where there was a good enough gain in generation to balance this increased tariff), the gain in generation here is marginal. Hence a good 0.021 USD Cents / kWh increase in tariff is required as compared to the base case if the Base case IRR is to be achieved.

The Business model 2, pertains to an established and large fish farming company getting into Solar generation. The company would setup a subsidiary company for solar project development to whom it would lease the space. The basic structure is the same as in model 1, the only difference is that a solar development company in this case is leasing land from its own parent company rather than other fish farms as in model 1. The dynamics of this model are similar to model 1 and hence the result is also the same.

**Assumptions and Analysis for Multipurpose use of RE with Animal farms**

The Animal farms have two possible areas, i.e. shed area and the Grass production area for solar installation. However, the shed area is not suitable for large grid connected capacity. Thereforethe financial analysis has been done for the grass production area alone which is quite similar to the Agricultural fields. Despite the similarity, the numbers could be different as the Grass has a shade tolerance of only 30% as compared to vegetables that had a shade tolerance of 40%. Also, the grass is much more profitable business than vegetable production. The methodology of financial analysis as well as business models are the same as considered for the multipurpose use of agricultural land with RE.

**Table 0-7: – Assumptions for base case in multipurpose use of land with Grass fields**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1$^{st}$ year<br>0.8% per year from 2$^{nd}$ to 20$^{th}$ year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |

| Particulars | Assumptions |
|---|---|
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 100,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWp |

For Business model 1, the tariff shall be almost the same as the base case. The reason is that in this business model, the land required per MW of Solar as well as Capex are increasing as compared to the base case, that increase the Tariff. But the generation is also increasing which is balancing this increase and hence the computed Tariff shall be almost the same as the base case.

For the Business model 2, the tariff comes out to be the same as the base case. This model pertains to an established grass producing company or a big grass producing farmer getting into Solar power generation. The company would setup a subsidiary company for solar project development to whom it would lease the land. The basic structure is the same as in model 1, the only difference is that the solar development company in this case is leasing land from its own parent company rather than other grass producers as in model 1. The dynamics of this model are similar to model 1 and hence the result is also the same.

For the Business model 3 also, the tariff comes out to be the same as the base case. The reason is thatthe solar and grass production business have almost equal returns and therefore almost similar tariff is required to get an IRR equal to the base case.

This is unlike the case of multipurpose use of Agricultural farms because Grass production has much better returns as compared to vegetable production. Looking at this in practical sense, the Solar development companies may have a very limited interest to get into this business model.

## POTENTIAL OF MULTIPURPOSE USE

The total potential of multipurpose use of land with RE for three basic trades i.e. Agriculture farms, animal farms and fisheries put together is 22,616 MW. The individual potential of three trades is given below.

**Potential of Agrivoltaics (Multipurpose use with Agricultural farms)**

The total area of agricultural land under 40% shade tolerant crops in Bangladesh is 12,68,424 acres

An analysis of irradiance map of Bangladesh, shows that atleast 50% of nation has yearly GHI of over 1700 kWh /sqm which is suitable for solar PV installation. So considering 50% of the above area as suitable for multipurpose use, the suitable area is around 6,34,212 acres.

For agricultural fields the area required per MW of solar – 4.2 acres

So, theoretical potential is 6,34,212 /4.2 = 1,51,003 MW

However, in addition to satisfying the conditions of good radiation and shade tolerance of crops, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e. around 21 acres must be available either in a single farm (not very likely) or as a combination of small fields located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 10% of 1,51,000 MW theoretical potential will meet this criteria and hence the practicable potential would be around 15,100 MW.

**Potential of Agrivoltaics (Multipurpose use with fish farms)**

The total pond area good for multipurpose use with RE is 3,16,884 acres

50% of this area having good radiation (as explained in the previous section) = 1,58,442 acres.

For fish ponds the area required per MW of solar – 6.6 Acres

So, theoretical potential is 1,58,442 / 6.6 = 24,006 MW

However, in addition to satisfying the conditions of good radiation, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e. around 33 acres must be available either in a single farm (not possible) or as a combination of small farms located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 5% of 24,006 MW theoretical potential will meet this criteria and hence the practicable potential would be around 1200 MW.

**Potential of Multipurpose use of RE with animal farms**

The total area of land producing grass with 30% shade tolerance is 9 Lakh acres.

50% of this area having good radiation (as explained in the previous section) = 4.5 lakh acres.

For grass field the area required per MW of solar – 5.7 acres

So, theoretical potential is 4,50,000 / 5.7 = 78,947 MW

However, in addition to satisfying the conditions of good radiation and shade tolerance of grass, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e. around 28.5 acres must be available either in a single farm (not very likely) or as a combination of small fields located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 8% of 78,947 MW theoretical potential will meet this criteria and hence the practicable potential would be around 6316 MW.

# 1.0 INTRODUCTION

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

To fulfill the Government of Bangladesh's (GoB) vision of sustainable development it is well acknowledged that development of RE will play a vital role. As such the government is committed to increase the RE penetration in the power generating eco system.

Development of RE generation facilities especially solar and wind require vast land. Bangladesh being an agrarianand a densely populated country that is dependent on agriculture and related activities, the availability of land for other purposes becomes a challenge. According to *World Population Review2022* statistics, Bangladesh is the 11$^{th}$ most densely populated (1138/km$^2$) countries in the world (refer Fig 1-1 below). Considering this land crunch, it would be prudent and the need of hour to co-locate the land extensive RE based power plants that is used not only for power generation but also for farming to sustain the economy of the country. With this background GoB is examining the option of multiple use of land for electricity generation through renewable sources.

With this end in view Power Cell, Bangladesh intends to hire an international consultant to study the feasibility of multiple use of land in developing RE projects.

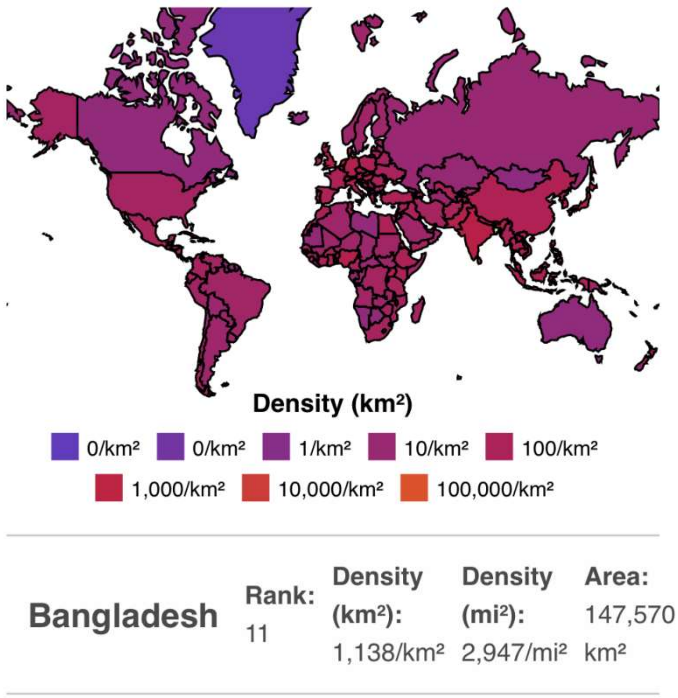



**Figure1-1 - Countries by Population Density 2022**

# 1.2 APPROACH AND METHODOLOGY

## 1.2.1 Approach

### 1.2.1.1 General

RE projects like solar and wind need vast land for development. For highly populous country such as Bangladesh availability of land is a major barrier for development of such projects. Also in Bangladesh majority of land is agricultural land and agriculture is a source of income for majority of population. In this scenario option of using land for development of RE projects as well as for farming can be an ideal solution for balancing the energy and food security need of the country.


**Figure1-2–Evaluation Factors**

### 1.2.1.2 Factors for Evaluation

Potential

Assessment of potential for developing such projects will require detail study of availability of RE resources at various areas of the country and also farming profile in such areas. This potential will be a basis for drawing various scenarios for implementing multiple use of land.

Farming Pattern

Farming pattern is a major factor for drawing feasibility of implementing multiple use of land concept. Whether existing farming and RE can co-exist or there is a requirement of crop switching will need to be analysed.

RE Technology Re-engineering

Technology choice and further re-engineering need to be properly assessed to support such projects. Re-engineering i.e modification in existing base structure of the PV plants, layout planning etc. will play a major role in drawing feasibility of such idea.

Economic Aspects

The economic aspects can be assessed considering various benefits the land owner or the developer will get from such projects. There may be more financial benefits to the farmer if the he can lease out his land to developer and simultaneously continue doing farming. However there will be some financial impacts if he needs to do crop switching. From the developer perspective there will be extra cost he may have to incur due to re-engineering power generation facilities for accommodating farming.

## 1.3 METHDOLOGY

### 1.3.1 Data Collection

As a first step, our consultant team will use their local experience in identifying land parcels across the country, including hinterlands of the country where agricultural practices are carried out in large parcels of land. STEAG, partnered with TECHNOBIN, will utilize TECHNOBIN's local presence and experience in mapping out the regions that can be focused and approached, considering the short duration of the assignment. Suitable RE technologies will be identified that can be installed along with these existing agricultural activities. The RE resource for example Solar resource or Wind resource available will be important criterion for identifying the suitability of co-location. The areas having moderate to good and high resources will be given preference as these will have higher chances of being feasible projects. In the good resources areas, special effort shall be made to identify the crops that are not constrained by low sunlight and if required alternate crops will be suggested depending upon their suitability and market ability. heartlands

### 1.3.2 Site Visit

The team will visit the sites where RE projects are installed / under implementation / under planning and capture pictures of available land and prepare expert reports of agricultural activities that can be carried out and can be co-located with these RE technologies. For the above activity, our team will interact with RE related organizations such as Power Cell, SREDA, Power Cell (Client), BPDB, BREB and other utilities to understand RE projects as well as Agriculture Ministry, BADC, BRRI, BARI, BARC, Ministry of Fisheries, Ministry of Livestock etc. to collect information to identify cultivation, animal husbandry and fish farming nature of Bangladesh. The team will then work to analyze possible options to adopt those activities in RE projects considering all aspects.

The team, at this stage, will also focus on agriculture value chain that can be supported through RE technology (along with crops; animals and fisheries activities cultures of Bangladesh). This will provide an opportunity to co-locate RE with real importance and enhanced technical use. The renewable energy experts carry years of experience in renewable energy domain and their expertise in technical, financial, regulatory and commercial aspects of the projects will be utilized to gain better insight of the subject.

### 1.3.3 Technology Analysis

Our team will study the available technologies that are used under similar conditions for multipurpose use and list out the design changes that are needed to adopt these technologies for various identified land parcels and multipurpose applications. The adoption process will also consider the land optimization as this is the most important consideration in Bangladesh.

The adoption process detailing will lead to a new and optimum design as would be suitable for Bangladesh. Once the new designs are ready, detailing will also be done for installation as well as operation and maintenance of the plants that would be created using these designs. Special considerations in view of structural changes and also the safe operation of RE plants in view of the wet area will also be detailed out.

### 1.3.4 Risk Assessment

At this stage strong focus will be given to risk assessment which includes risks related to RE project planned and risk to the agricultural activity carried out in the field. The risks to RE installation for example increased rusting of structure in view of the wet conditions or possibility of cable getting damaged due to other activities or a possible enhanced performance degradation shall be detailed out. Also the risks to other activities that are posed by the RE installations e.g. a possible electrocution of persons working or contamination of land / water around would also be detailed. Based on these a detailed matrix will be prepared. This matrix will also capture the likeliness of risk to happen and the proposed mitigation plan.

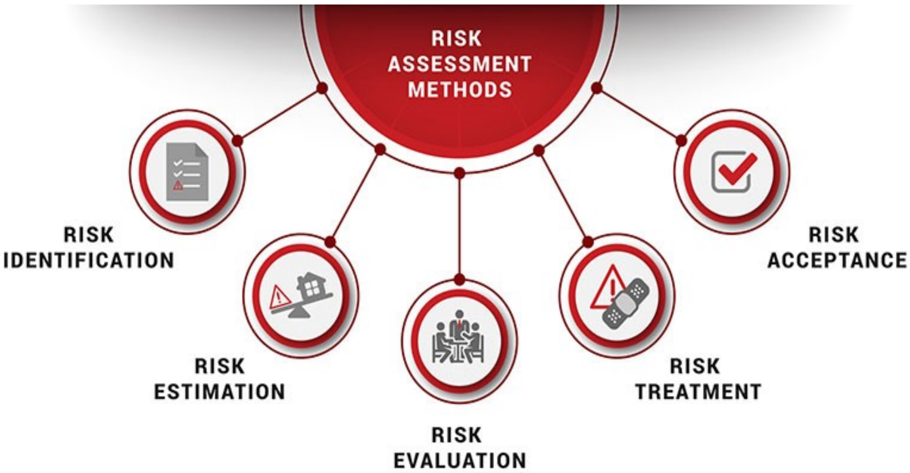



**Figure1-3–Risk Assessment methods**

### 1.3.5 Review of Standard Document

Once the feasible RE technologies are identified to be co-located with agriculture animal husbandry of fisheries activities in Bangladesh, the team will work on designing the required tender documents and PPA and IA (bringing in international experience of designing these documents to cover risks or both parties as well as to bring in a competitive advantage). Three sample / model tenders will be prepared for co-location of Solar PV one each for co-location with agriculture, animal husbandry and fisheries. The PPA may be common for all the three.

If required the exercise may be done for other RE technologies also.

Considering limited deployment of RE in Bangladesh as of date but a vision to add substantial RE in energy mix by 2040,will need strong regulatory steps to bring in increased interest from private players. The same will be considered in designing the required tender documents and PPA documents. One of the most important points that will be considered is payment security and reducing the developer risk, which will bring in increased participation. Hence, our learning from developed countries will be able to add advantage in designing PPA and tender documents.

### 1.3.6 Financial and Economic Analysis

Finally, the team will conduct financial and economic assessment of the proposed RE technology co-located with the agricultural activities. For the same, detailed financial model will be prepared to capture the inputs for each of the proposed RE technology followed by sensitivities on capital cost, operational costs, preferred range of tariff, etc. Three financial models will be prepared for co-location of Solar PV one each for co-location with agriculture, animal husbandry and fisheries. If required the exercise may be done for other RE technologies also. The financial models will consider the Cost as well as revenue both from the RE source as well as the other activity. In some cases a split modelling may be required because the beneficiary / developer of RE technology may be different from the farmer.

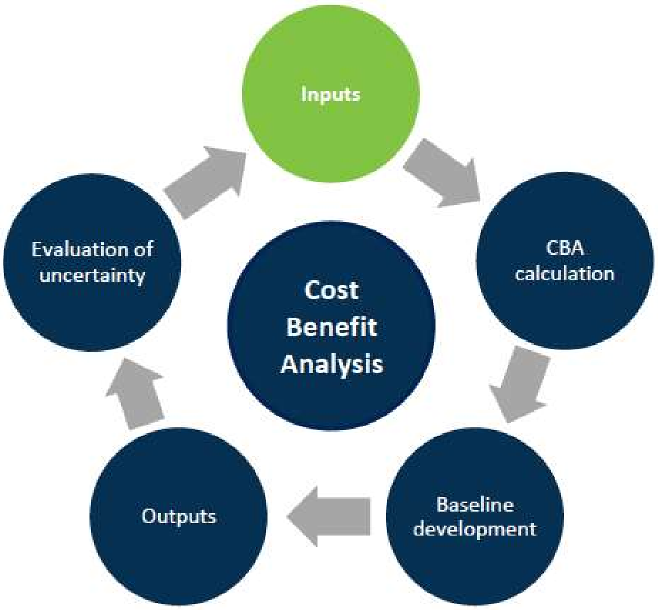



**Figure1-4: Financial and Economic Analysis**

### 1.3.7 Environmental Analysis

Next step shall include environmental and legal due diligence where Bangladesh laws and regulations will be referred to evaluate the legal and institutional aspects of the land utilities for multipurpose use. Based on our experience, the team will also propose recommendations to be considered in order to manage environmental disaster, consider social, legal and environmental aspects in order to implement RE projects in the agricultural land alongside the agricultural activities.


**Figure1-5: Environmental Analysis**

### 1.3.8 Case Study

Once our assessment of identifying feasible RE technology and studying its technology, commercial legal viability, the team will refer to some International use studies to bring in comfort to the regulators to propose similar models in Bangladesh.

### 1.3.9 Analysis and Report

A detail techno-economic feasibility analysis will be done to draw a conclusion on adoption of the multi-purpose use of land concept.

The main aspects which the report will cover will be:

i. Potential Assessment for multipurpose use of land
ii. Re-engineering aspects for such projects
iii. Farming identification and crop switching aspects
iv. Cost-Benefit analysis
v. Formulation of Business Model
vi. Conclusion

# 2.0 SELECTION OF SUITABLE LAND

## 2.1 BASIS FOR SELECTION OF LOCATION

The choice of areas for multipurpose land use can be made on the basis of following criteria:

- The RE resource availability in that area
- The shade tolerance of the species (crop or fish or animal or anything else) that has to exist below the solar panels.
- The negative impact (loss of yield) of shade on the particular species
- The total or contiguous area available in an individual farm / pond or in close vicinity for Solar plant development
- The evacuation infrastructure in the area

## 2.2 ANALYSIS OF RE RESOURCE

### 2.2.1 Solar Resource and Potential

Bangladesh has a reasonably good solar resource and potential. The following two maps show the Solar GHI and Solar PV potential in Bangladesh. These two mapshave been obtained from the "Global Solar Atlas 2.0, a free, web-based application, developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info.

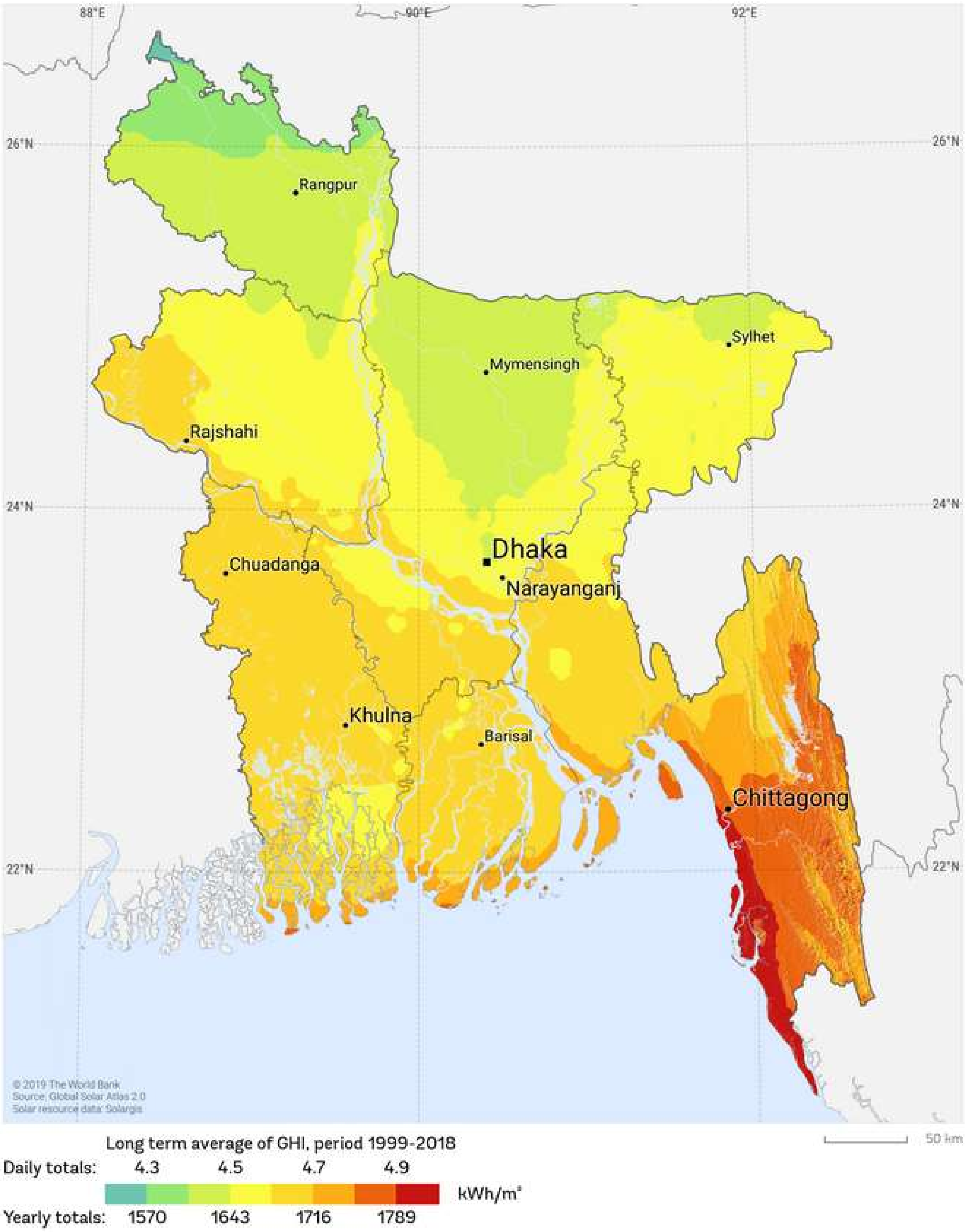



**Figure2-1: Global Horizontal Irradiation (GHI) of Bangladesh**

As is clear from the map above, more than half of Bangladesh receives more than 1700 kWh/m$^2$ of GHI on an annual basis. The Chittagong Zone and the Southern coastal regions of Khulna and Barisal Zones are particularly good.

The middle part of the country is moderate in terms of Irradiation received while the upper regions are not so promising.

The map below shows the potential of Solar PV in Bangladesh in terms of units of power (kWh) produced per kWp of installation.

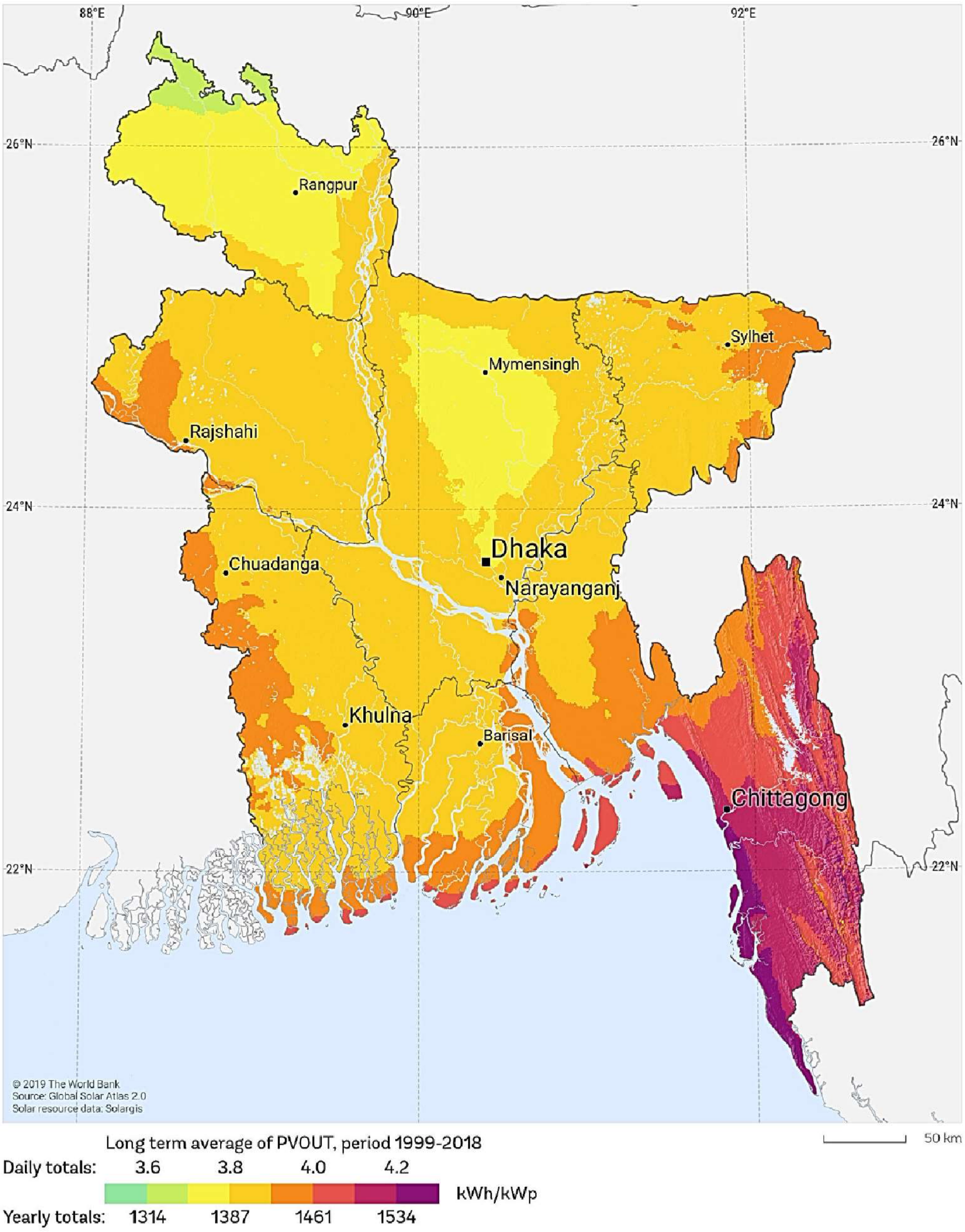


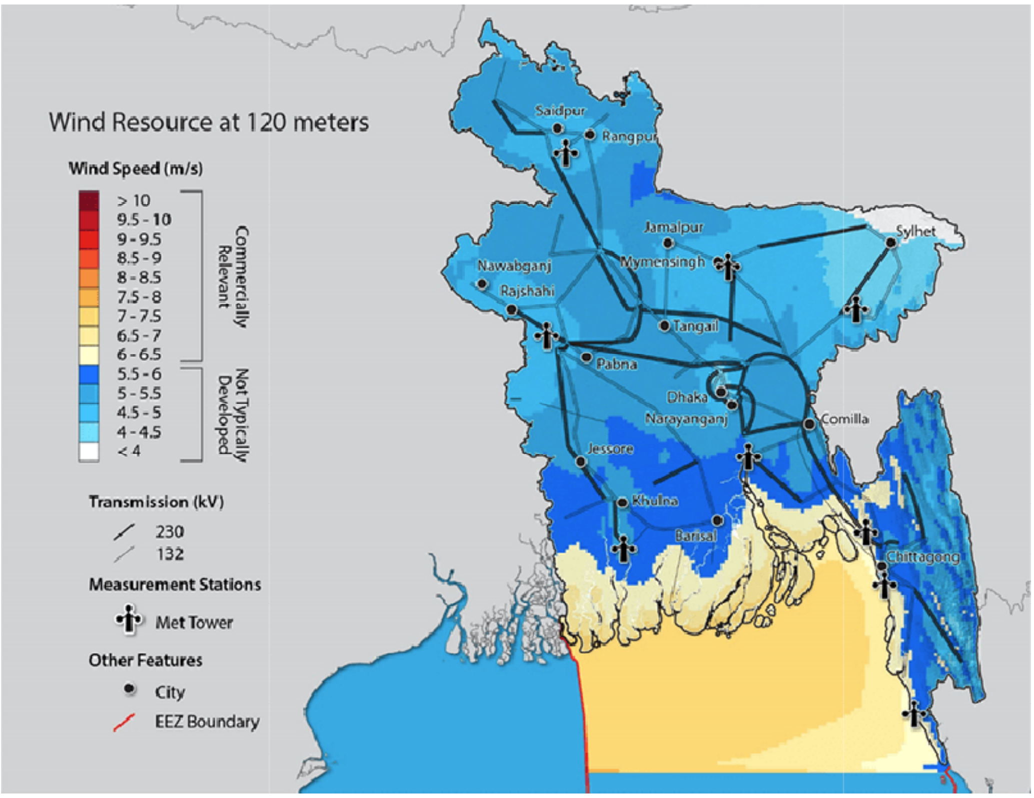

**Figure2-2: Solar Potential of Bangladesh**

As can be seen, the entire Chittagong, Western sides of Rajshahi, Chuadanga, and Khulna, the Southern coastal areas of Khulna and Barishal and the Eastern side of Sylhet are all good for solar PV installations.

### 2.2.2 Wind Potential

The wind resource availability in Bangladesh is not as good as solar but there does exist some opportunity especially on the Southern side near to the coast and off-shore.

As per a study done in 2018 by United States Agency for International Development (USAID) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), the Wind resource map of Bangladesh at 120m hub height is given below:




*Source: A study done by USAID and NREL*

**Figure2-3: Wind Resource Map of Bangladeshat 120m height**

The best wind speeds are available off the shore of Khulna, Barisal and Chittagong that are in the range of 7 to 7.5 m/s. On the shore of these Zones, 6 to 6.5 m/s is available which is also good for Wind farm development. The areas immediately adjacent to the coastal areas are also in the range of 5.5 to 6 m/s. Other than these, Rangpur has also some areas of 5.5 to 6 m/s. The other areas have relatively lower wind speeds and thus the wind farm development may not be feasible unless the site specific feasibility report suggests otherwise.

## 2.3 CRITERIA FOR SELECTION OF LAND FOR MULTIPURPOSE USE OF RE WITH AGRICULTURAL ACTIVITIES

The total land area in Bangladesh is 14.84 Mha (Million hectare) out of which about 9.503Mha is agricultural land. Several types of crops are cultivated and there is a wide difference between the types and quantum of crops cultivated in different divisions. Since the areas best suited for multipurpose land use are to be identified, it is important to analyse the distribution of different crops in various divisions.

### 2.3.1 Distribution of Crops in Different Divisions

The table below shows the distribution of cultivation of major crops in various divisionsof Bangladesh.

**Table 2-1: Division wise Area(ha) under cultivation for different crops**

| Division | Rice | Maize | Vegetable | Wheat | Pulses | Oilseeds | Potato | Sugarcane | Jute |
|---|---|---|---|---|---|---|---|---|---|
| Barisal | 995,666 | 2,592 | 40,000 | 8,642 | 260,004 | 41,015 | 15,440 | 3,014 | 15180 |
| Chittagong | 1,092,180 | 47,479 | 79,000 | 17,327 | 91,290 | 115,979 | 75,585 | 7,759 | 9344 |
| Dhaka | 541,200 | 38,135 | 80,000 | 124,896 | 213,466 | 355,777 | 79,127 | 24,205 | 268625 |
| Khulna | 962,731 | 122,802 | 67,000 | 118,976 | 200,361 | 119,953 | 32,616 | 22,155 | 204430 |
| Mymensingh | 799,561 | 15,630 | 45,000 | 20,758 | 25,686 | 93,161 | 36,356 | 17,029 | 42897 |
| Rajshahi | 788,028 | 146,082 | 76,000 | 207,332 | 223,962 | 404,074 | 267,712 | 87,173 | 128250 |
| Rangpur | 863,935 | 293,322 | 82,000 | 139,756 | 54,752 | 110,465 | 241,940 | 36,030 | 75940 |
| Sylhet | 906,167 | 1,175 | 34,000 | 6,692 | 4,796 | 8,710 | 16,648 | 2,947 | 1234 |

Data source - DAE, 2021

### 2.3.2 Shade Tolerance of Crops

One of the most important factors for location selection in multipurpose use of land is the shade tolerance of the Crops. Any shade tolerance level e.g. 30% means that the yield of the crop is not significantly impacted when the plant is shaded for 30% of the time during the sunshine hours. So, obviously the areas having crops with more shade tolerance are better suited for Agrivoltaics.

The shade tolerance level of various crops is given in the table below:

**Table 2-2: Shade tolerance level of various crops**

| Deep shade tolerance crops (up to 60%) | Moderate shade tolerance crops (up to 40%) | Lower shade tolerance crops (up to 20%) |
|---|---|---|
| Betel leaf, Taro | Vegetables- (Tomato, Carrot, Potato, Eggplant Pumpkin, Beets, Spinach, Broccoli, Lettuce, Radish, Cabbage and Cauliflower) and Spices- (Chili, Turmeric, Zinger,, Garlic; Fruits: Banana; Oil seeds: Pea nut, ground nut. | Cereals: Aus rice, Aman rice (Aromatic rice), Pulses (black gram, mash, moong and pigeon pea. |

### 2.3.3 Analysis

The crops under 60% shade tolerance category are minor crops and therefore will not be significant from the solar development standpoint. Also, the 20% shade tolerant category will also not be useful from solar perspective as any type of installation will cause more shade than 20%.

Therefore the most useful category of crops for being considered for multiple land use with solar will be the 40% shade tolerant category and therefore further detailing has been done for 40% shade tolerant crops from the point of view of their division wise distribution.

The table below shows the 40% shade tolerant crop area in different divisions:

**Table 2-3: Area under 40% shade tolerant crops in various divisions**

| Division | Vegetable | Potato | Total land area (Acres) | Area under 40% Shade tolerant crops (Acres) | 40%Shade tolerant as Percent of total land |
|---|---|---|---|---|---|
| Barisal | 40,000 | 15,440 | 13,22,520 | 55,440 | 4.2% |
| Chittagong | 79,000 | 75,585 | 33,90,855 | 1,54,585 | 4.6% |
| Dhaka | 80,000 | 79,127 | 20,59,374 | 1,59,127 | 7.7% |
| Khulna | 67,000 | 32,616 | 22,28,422 | 99,616 | 4.5% |
| Mymensingh | 45,000 | 36,356 | 10,58,406 | 81,356 | 7.7% |
| Rajshahi | 76,000 | 2,67,712 | 18,15,308 | 3,43,712 | 18.9% |
| Rangpur | 82,000 | 2,41,940 | 16,18,499 | 3,23,940 | 20% |
| Sylhet | 34,000 | 16,648 | 12,63,522 | 50,648 | 4% |

Data source - DAE, 2021

So the top four divisions from area point of view are the following:

1. Rajshahi
2. Rangpur
3. Dhaka
4. Chittagong

However, from the Solar resource point of view the top four divisions are the following:

1. Chittagong
2. Rajshahi
3. Dhaka
4. Rangpur

The ranking of the divisions considering both the factors i.e. the land area under 40% shade tolerant crops as well as solar resource shall be the following:

1. Rajshahi
2. Chittagong
3. Dhaka
4. Rangpur

## 2.4 MULTIPURPOSE USE OF RENEWABLE ENERGY WITH FISHERIES

Bangladesh has a large number of fish ponds. The total area of fish farms is around 4 lakh hectare.This is quite small as compared to the 11.13 Million hectare of agricultural land but looking but still large enough if seen on standalone basis. In the coming sections, the various aspects of fish farming and the suitability for multiple use with RE are discussed.

### 2.4.1 Fish Variety in Bangladesh

Bangladesh has several fish varieties which are under farming. The list of these Fish varieties is given in the table below:

**Table 2-4: List of Fish varieties under farming in Bangladesh**

| S. No. | Species | Scientific Name |
|---|---|---|
| 1. | Rui | *Labeo rohita* |
| 2. | Catla | *Catla catla* |
| 3. | Mrigal | *Cirrhinus cirrhosus* |
| 4. | Kalibaus | *Labeo calbasu* |
| 5. | Bata | *Labeo bata* |
| 6. | Ghania | *Labeo gonius* |
| 7. | Silver carp | *Hypophthalmichthys molitrix* |
| 8. | Grass carp | *Ctenopharyngodon idella* |
| 9. | Common carp | *Cyprinus carpio* |
| 10. | Other Exotic carp | |
| 11. | Pangus | *Pangasius pangasius* |
| 12. | Boal | *Wallago attu* |
| 13. | Aor | *Sperata aor* |
| 14. | Shol | *Chenna striatus* |
| 15. | Gazzar | *Chenna marulisu* |
| 16. | Taki | *Chenna punctatus* |
| 17. | Koi | *Anabas testudineus* |
| 18. | Shingi | *Heteropneustes fossilis* |
| 19. | Magur | *Clasius batrachus* |
| 20. | Tilapia | *Oreochromis mossambicus* |
| 21. | Nilotica | *Oreochromis niloticus* |
| 22. | Sarpunti | *Puntius sarana* |
| 23. | Thai punti | *Barbodes gonionotus* |
| 24. | Other inland fish | |
| 25. | Shrimp/Prawn (Penaeus monodon) | |
| 26. | Crab | |
| 27. | Cuchia | *Monopterus cuchia* |

Reference: Department of Fisheries (DoF), 2021. Yearbook of fisheries statistics of Bangladesh, 2019-2020. Department of Fisheries, Bangladesh

However, just like the crops, all fish variety are not shade tolerant. The shade tolerance is important because for multipurpose use of fish ponds or other water bodies, floating solar panels are to be installed. The floating solar panels may obstruct the natural light although partially. Therefore the variety of fish that does not get disturbed as a result of this shade have to be identified which can be referred to as shade tolerant fist variety.

### 2.4.2 Shade tolerant Fish variety in Bangladesh

The shade tolerant fish varieties are given in the table below:

**Table 2-5: Shade tolerant fish variety**

| S. No. | Fish | Scientific Name |
|---|---|---|
| 1. | Rui | *Labeo rohita* |
| 2. | Nile Tilapia | *Oreochromis niloticus* |
| 3. | Tilapia | *Oreochromis spp.* |
| 4. | Vennaei Prawn | *Litopenaeus vannamei* |
| 5. | Prawn | *Penaeus monodon* |
| 6. | Singhi | *Heteropneustes fossilis* |
| 7. | Magur | *Clarias batrachus* |
| 8. | Pabda | *Ompok pabda* |
| 9. | Koi | *Anabas testudineus* |
| 10. | Pangus | *Pangasianodan hypophthalmus* |
| 11. | Small indigenous species, e.g. Bele | |

| S. No. | Fish | Scientific Name |
|---|---|---|
| 12. | Carp | *Cyprinus carpio* |
| 13. | Crabs | |
| 14. | Lobsters | |
| 15. | Mussels, Clams, etc. | |
| 16. | Salmon | |
| 17. | Trout | |
| 18. | Bass | |

The Pond area for fish varieties in different divisions of Bangladesh is given in the table below which is also categorized as per the type of fish farming.

**Table 2-6: Pond area for fish varieties in Bangladesh – Division wise**

| S. No. | Division | Extensive (<1.5 MT/Ha) | Semi-intensive (1.5 – 4.0 MT/Ha) | Intensive >4-10 MT/Ha | Highly intensive >10.0 MT/Ha | Total (Ha) |
|---|---|---|---|---|---|---|
| 9. | Dhaka | 2133 | 25712 | 15578 | 1688 | 45111 |
| 10. | Mymensingh | 1181 | 16403 | 16623 | 10726 | 44933 |
| 11. | Khulna | 9570 | 31426 | 13835 | 2583 | 57414 |
| 12. | Barishal | 2656 | 23342 | 6319 | 40 | 32357 |
| 13. | Rangpur | 452 | 29640 | 11313 | 640 | 42045 |
| 14. | Rajshahi | 515 | 45959 | 23674 | 1336 | 71484 |
| 15. | Chatttogram | 10350 | 60140 | 18264 | 1266 | 90020 |
| 16. | Sylhet | 5749 | 11028 | 4223 | 133 | 21133 |
| | Total | 32606 | 243650 | 109829 | 18412 | 404497 |

Reference: Department of Fisheries (DoF), 2021. Yearbook of fisheries statistics of Bangladesh, 2019-2020. Department of Fisheries, Bangladesh

### 2.4.3 Analysis

Having seen the total pond area in different divisions, it is also important to see the sizes of individual ponds and distribution of these ponds in close vicinity to each other to assess the potential of multipurpose use. The context is that about four acres of area is required for 1 MW of floating solar installation. Also, no more than 40% of pond area should be covered for installation of panels (to allow for feeding, fish catching etc.). This means thateven if a 5 MW plant is being considered, then also more than 30 acres of area is required.

As far as fish farming in Bangladesh is concerned, the typical pond size is around 70 to 100 ft long, 35 to 50 ft wide and 4-5 ft water deep. The ratio between the length and width of the pond should be maintained between 2:1 to 4:1 (the width should be less than half the length). This is to provide the fish long stretches of swimming and feeding space and also for easy netting.

**Figure 2-4: JALSHIRI DAIRY FARM AND FISHERIES Trishal, Mymensingh**

The small size of the ponds means that individual ponds are much smaller than the required area and therefore the places good for multipurpose use of these ponds for solar installations would be the ones where there are a number of ponds in clusters or close vicinity.

**Figure 2-5: Jalshiri Dairy Farm and Fisheries Trishal, Mymensingh – Picture showing nearby ponds**

As far as large water bodies (that may be having enough area to have individual plants) are concerned, there are a few in which other factors for suitability of solar installations are being studied. These include the larger water bodieslike wetlands, beels and lakes. For example, Dhanmondi Lake is 3 km in length, 35-100m in width, with a maximum depth of 4.77m and the total area of the water body is 37.37 ha. Another example isChalan Beel, which is one of the largest inland depressions of marshy character and also one of the richest wetland areas of Bangladesh. During rainy season, it covers an area of about 368 sq km.

**Figure 2-6: Chalan Beel**

While in such large water bodies, floating solar is always possible but because of the large area, it will be possible to find separate areas for fishing and separate place for installing solar. It will therefore not come under the multipurpose use and rather come under floating solar.

**Suitability of commercial fish ponds for putting solar panels:**

The fish ponds with clear banks not having trees and having a minimum1500 sqm area that can be used for solar installation are suitable for multipurpose use.

**Figure 2-7: Fish pond with no trees at banks – JALSHIRI DAIRY FARM AND FISHERIES Trishal, Mymensingh**

The fish ponds with tall trees near banks are not suitable for multipurpose use.

**Figure 2-8: Picture Fish pond with trees at banks – Trishal Mymensingh**

A proposed design for solar in these fish ponds is given in the section on Plant design.

## 2.5 MULTIPURPOSE USE OF RE WITH ANIMAL HUSBANDRY ACTIVITIES

Just like agriculture and fisheries, animal farms also have prima facie a reasonable potential for multipurpose land use with RE.Most types of Animal Husbandry locations (farms) will require a covered area (some kind of a shed or a building) and an uncovered area. The covered area is used for housing the animals while the open area is used for growing feed for the animals. The total shed area in various farms in Bangladesh is estimated to be around 27,000 acres while the open area is around 13 Lakh acres. All farms may not have the open areas. In case of small farm areas, fodder or grass are purchased or collected from other farmers and in case of large farm containing abundant area, fodder/grass are produced in enough quantity within the farm.

Both type of areas i.e. covered as well as the uncovered areas could be suitable for solar panels installation. The shed area could be a proper RCC roof or it could even be a Shed with sheet metal roof of suitable strength. These areas can be utilized for installation of rooftop systems maybe after a suitable strengthening of the roof. The open areas can be utilized for modified ground mounted plants.

### 2.5.1 Animals and related farm area (covered area) in Bangladesh

As mentioned in the previous sections, there is an estimate of the covered area in different types of animal farms in Bangladesh. The table below shows the number of animals under farming in Bangladesh.

Data Source: BBS, 2021-22; Department of Livestock Services (DLS), Bangladesh.

Acknowledgement: Dr. Hossan Md. Salim, Planning Section, Department of Livestock Services (DLS), Dhaka, Bangladesh.

Further, the approximate shed area has been calculated using the number of animals and the approximate area required for housingdifferent animals.

**Table 2-7: Number of animals and farm area in Bangladesh**

| Animal | Nos. in Bangladesh | Shed area required in Sq. Ft/Animal | Total Area Sq. ft | Area in acres |
|---|---|---|---|---|
| Cattle | 2,46,99,707 | 15 | 37,04,95,607 | 8,505.41 |
| Buffalo | 15,08,022 | 15 | 2,26,20,328 | 519.29 |
| Sheep | 37,51,529 | 6 | 2,25,09,175 | 516.74 |
| Goat | 2,67,74,314 | 6 | 16,06,45,885 | 3,687.92 |
| Chicken | 31,18,00,032 | 1.5 | 46,77,00,049 | 10,736.92 |
| Duck | 6,38,44,978 | 2 | 12,76,89,955 | 2,931.36 |

| Animal | Nos. in Bangladesh | Shed area required in Sq. Ft/Animal | Total Area Sq. ft | Area in acres |
|---|---|---|---|---|
| | 43,23,78,583 | | **Total** | **26,897.64** |

### 2.5.2 Division wise distribution of animals and the farm areas:

The division wise distribution of the farm area is important to study because the different divisions have different Solar resource and the divisions having more farm area and better solar resource will be good candidates for multipurpose land use. The area in any farm depends upon the types of animals it is housing and therefore the numbers of animals of different types are analysed division wise. The division wise and Zila wise number of animals is given in the table below:

**Table 2-8: Number (in Lakhs) of farm animals in Bangladesh at Zila level**

| Division | Zila | Cattle | Buffalo | Goat | Sheep | Chicken | Duck |
|---|---|---|---|---|---|---|---|
| Barisal | Barguna | 1.92 | 0.49 | 1.19 | 0.12 | 53.01 | 13.77 |
| | Barisal | 3.42 | 0.79 | 2.36 | 0.11 | 60.31 | 18.35 |
| | Bhola | 2.63 | 1.26 | 2.74 | 0.11 | 59.68 | 26.98 |
| | Jhalokati | 1.15 | 0.39 | 0.77 | 0.00 | 30.43 | 8.07 |
| | Patuahkali | 5.73 | 1.38 | 2.15 | 1.15 | 69.49 | 23.92 |
| | Pirojpur | 1.42 | 0.16 | 0.76 | 0.00 | 50.88 | 11.14 |
| Chittagong | Bandarban | 0.94 | 0.14 | 0.72 | 0.00 | 18.16 | 0.16 |
| | Brahmanbaria | 3.16 | 0.18 | 1.15 | 0.73 | 52.94 | 15.63 |
| | Chandpur | 2.30 | 0.14 | 0.91 | 0.11 | 45.75 | 11.87 |
| | Chittagong | 8.06 | 0.60 | 1.68 | 0.10 | 82.10 | 13.79 |
| | Comilla | 7.12 | 0.20 | 2.43 | 0.32 | 107.17 | 39.70 |
| | Cox's bazar | 1.66 | 0.76 | 1.04 | 0.30 | 38.98 | 2.03 |
| | Feni | 1.07 | 1.09 | 0.22 | 0.11 | 29.39 | 10.96 |
| | Khagrachhari | 1.54 | 0.36 | 2.53 | 0.11 | 24.25 | 0.85 |
| | Lakshmipur | 1.71 | 0.32 | 1.10 | 0.12 | 46.31 | 16.61 |
| | Noakhali | 3.23 | 0.66 | 1.27 | 0.32 | 75.74 | 31.38 |
| | Rangamati | 1.48 | 0.15 | 1.66 | 0.00 | 26.39 | 1.74 |
| Dhaka | Dhaka | 2.29 | 0.19 | 0.81 | 1.33 | 27.91 | 3.43 |
| | Faridpur | 2.61 | 0.29 | 2.34 | 0.11 | 37.52 | 5.94 |
| | Gazipur | 3.26 | 0.28 | 2.42 | 0.30 | 52.17 | 5.89 |
| | Gopalgonj | 2.15 | 0.02 | 0.71 | 0.07 | 21.23 | 8.53 |
| | Jamalnpur | 5.31 | 0.16 | 2.38 | 1.16 | 61.26 | 5.78 |
| | Kishoregonj | 3.28 | 0.08 | 0.96 | 0.29 | 55.09 | 10.78 |
| | Madaripur | 1.44 | 0.01 | 0.62 | 0.00 | 26.76 | 4.19 |
| | Manikgonj | 4.67 | 0.05 | 1.56 | 1.13 | 37.15 | 2.77 |
| | Munshigonj | 1.03 | 0.07 | 0.67 | 0.30 | 18.67 | 1.96 |
| | Mymensingh | 9.34 | 0.04 | 4.74 | 0.34 | 143.82 | 23.27 |
| | Narayangonj | 0.80 | 0.03 | 1.04 | 0.31 | 21.14 | 2.89 |

| Division | Zila | Cattle | Buffalo | Goat | Sheep | Chicken | Duck |
|---|---|---|---|---|---|---|---|
| | Narshigdi | 1.91 | 0.02 | 1.52 | 0.00 | 42.48 | 6.28 |
| | Netrokona | 4.87 | 0.02 | 1.34 | 0.38 | 54.00 | 12.55 |
| | Rajbari | 1.71 | 0.02 | 2.41 | 0.00 | 32.42 | 3.21 |
| | shariatpur | 1.64 | 0.01 | 1.70 | 0.11 | 41.25 | 10.98 |
| | Sherpur | 2.97 | 0.05 | 1.80 | 0.33 | 52.44 | 4.65 |
| | Tangail | 6.54 | 0.18 | 3.69 | 1.80 | 84.06 | 11.97 |
| Khulna | Bagerhat | 3.27 | 0.19 | 3.19 | 0.32 | 45.88 | 10.92 |
| | Chuadanga | 2.21 | 0.18 | 12.34 | 0.31 | 31.21 | 6.29 |
| | Jessore | 6.53 | 0.15 | 10.05 | 0.39 | 58.75 | 17.05 |
| | Jhenaidah | 4.94 | 0.02 | 11.42 | 0.11 | 48.24 | 9.42 |
| | Khulna | 2.83 | 0.29 | 4.03 | 1.57 | 32.46 | 9.56 |
| | Kushtia | 5.65 | 0.12 | 12.42 | 0.59 | 48.22 | 3.28 |
| | Magura | 2.39 | 0.00 | 4.03 | 0.00 | 27.82 | 2.85 |
| | Meherpur | 1.67 | 0.13 | 10.82 | 0.00 | 21.92 | 4.63 |
| | Narail | 1.43 | 0.14 | 1.15 | 0.00 | 21.01 | 4.54 |
| | Satkhira | 3.98 | 0.16 | 5.85 | 0.97 | 42.07 | 11.10 |
| Rajshahi | Bogra | 8.08 | 0.16 | 5.91 | 1.86 | 94.98 | 14.65 |
| | Joypurhat | 2.18 | 0.03 | 13.76 | 0.30 | 30.18 | 4.96 |
| | Naogaon | 8.59 | 0.20 | 13.07 | 1.98 | 95.03 | 21.32 |
| | Natore | 2.92 | 0.07 | 11.30 | 1.16 | 47.99 | 7.50 |
| | Chapai Nawabgonj | 2.18 | 0.22 | 9.46 | 0.40 | 21.34 | 3.37 |
| | Pabna | 7.69 | 0.22 | 10.44 | 0.40 | 52.90 | 5.13 |
| | Rajshahi | 3.90 | 0.22 | 13.07 | 1.57 | 65.71 | 12.44 |
| | Sirajgonj | 9.40 | 0.12 | 4.77 | 1.72 | 53.71 | 13.93 |
| Rangpur | Dinajpur | 9.28 | 0.09 | 5.56 | 1.85 | 94.16 | 21.66 |
| | Gaibandha | 6.72 | 0.15 | 7.16 | 1.78 | 62.93 | 11.85 |
| | Kurigram | 5.52 | 0.12 | 6.20 | 1.83 | 56.93 | 9.08 |
| | Lalmonirhat | 4.26 | 0.14 | 3.60 | 1.15 | 30.25 | 2.39 |
| | Nilphamari | 6.47 | 0.13 | 3.40 | 0.61 | 47.06 | 4.53 |
| | Panchagarh | 2.70 | 0.05 | 6.11 | 0.60 | 29.50 | 2.63 |
| | Rangpur | 7.23 | 0.04 | 10.01 | 1.55 | 85.21 | 10.71 |
| | Thakurgaon | 4.91 | 0.08 | 6.57 | 0.00 | 42.12 | 1.80 |
| Sylhet | Habiganj | 4.51 | 0.04 | 1.30 | 0.40 | 38.45 | 9.50 |
| | Maulvibazar | 2.59 | 0.19 | 1.85 | 0.31 | 27.53 | 5.85 |
| | Sunamganj | 3.69 | 0.20 | 1.18 | 1.49 | 39.13 | 15.33 |
| | Sylhat | 4.93 | 0.60 | 2.28 | 0.60 | 44.90 | 8.11 |
| Total | Total | 246.99 | 15.08 | 267.74 | 37.51 | 3118.00 | 638.44 |

Data Source: BBS, 2021-22; Department of Livestock Services (DLS), Bangladesh.

Acknowledgement: Dr. Hossan Md. Salim, Planning Section, Department of Livestock Services (DLS), Dhaka, Bangladesh.

From the above two tables, the covered area of farms in different divisions of Bangladesh is calculated and is given in the table below:

**Table 2-9: Divisionwise Covered farm area in Acres for different farm animals in Bangladesh as derived from the previous table**

| Division | Cattle | Buffalo | Goat | Sheep | Chicken | Duck | Total |
|---|---|---|---|---|---|---|---|
| Barisal | 560 | 154 | 137 | 21 | 1,115 | 469 | 2,457 |
| Chattogram | 1,111 | 159 | 203 | 31 | 1,884 | 664 | 4,052 |
| Dhaka | 1,921 | 53 | 423 | 110 | 2,787 | 574 | 5,869 |
| Khulna | 1,202 | 48 | 1,037 | 59 | 1,300 | 366 | 4,011 |
| Rajshahi | 1,548 | 43 | 1,127 | 129 | 1,590 | 382 | 4,819 |
| Rangpur | 1,622 | 28 | 670 | 129 | 1,543 | 297 | 4,289 |
| Sylhet | 541 | 36 | 91 | 38 | 517 | 178 | 1,401 |
| Total | 8,505 | 519 | 3,688 | 517 | 10,737 | 2,931 | 26,898 |

### 2.5.3 Analysis

From the point of view of area availability, the top four divisions are the following:

1. Dhaka
2. Rajshahi
3. Rangpur
4. Chittagong

However, from the Solar resource point of view the sequence would be the following

1. Chittagong
2. Rajshahi
3. Dhaka
4. Rangpur

The combined rating considering the land area under animal farming as well as solar resource shall be the following:

1. Rajshahi
2. Dhaka
3. Chittagong
4. Rangpur

Having seen the total farm area in different divisions, it is also important to see the sizes of individual farms and distribution of these farms in close vicinity to each other to see the potential of multipurpose use. The context is similar to Agriculture and fisheries that about 3.2 acres is required for 1 MW of solar installation. This means that even if a 5 MW plant is being considered, then also more than 15 acres of farm area is required.

By and large such large farms may not be available and the majority of them will be much smaller. This means that majority of individual farmsmay not be suitable for MW level installations and therefore the places good for multipurpose use of these farms for solar installations would be the ones where there are a number of farms in clusters or close vicinity.

As far as large farms(that may be having enough area to have individual plants) are concerned, there are a few e.g. Savar Dairy and cattle breeding farm, and another one near to Padma bridge. These large farmshouse lots of animals as well as fodder/ grass production areas and other related plants.

The American dairy at Ghazipur was visited and relevant data regarding the shed and the grass production area was collected.


**Figure 2-9: American dairy at Ghazipur**

The following data pertains to the shed area required to house the animals

**Table 2-10: American dairy Data**

| No. of dairy cow | Av. Milk production | Dry cow & pregnant cow | Total milk production | | Shed Area |
|---|---|---|---|---|---|
| 154 | 12.44 litre/cow | 141 | 1917 litre | | 295cattleX15sq ft=4425 sq ft |
| Total cow | Heifer | Calf | Total | | |
| 279 | 118 | 210 | 607 | | Heifer 118X12sqft= 1416 sq ft Calf210X9sqft= 1890 sq ft |
| Breeding bull | Total bull | | | | |
| 63 | 113 | | | | 113X80sqft= 9040 sq ft |

| No. of dairy cow | Av. Milk production | Dry cow & pregnant cow | Total milk production | | Shed Area |
|---|---|---|---|---|---|
| Male Goat (Breeding buck) | Breeding kids | Breeding Doe (female) | Total | | |
| 27 | 89 | 44 | 160 | | 160X6sqft= 960 sqft |
| Boar buck | Boar goat | Boar male kids | Boar female kids | Total | |
| 125 | 240 | 140 | 100 | 605 | 605X6sqft= 3630 sqft |
| Oasis sheep | Oasis kids | Others | Total sheep | | |
| 120 | 44 | 64 | 228 | | 228X6sqft= 1368 sqft |
| Dorpar sheep | Dorpar lamb (Growing) | Dorpar male lamb | Dorpar female lamb | Total | |
| 50 | 12 | 73 | 29 | 164 | 164X6sqft= 984 sqft |
| Murrah Buffalo (Bull) | Female buffalo | Buffalo calves (male) | Buffalo calves (female) | Total | |
| 16 | 11 | 05 | 05 | 37 | 37X30sqft= 1110 sqft |

Data Source – American dairy

With the above the total shed area is around 25,000 sq ft. or 0.57 acre.

**Figure 2-10: A typical shed at American Dairy**

For feeding these animals around 15 to 20 tonnes of grass is required on daily basis and the area available for this is around 60 Acres which is enough.

**Figure 2-11: A grass field**

A detailed analysis has been carried out to roughly estimate the total grass production area that might be available across the country. The first step is to estimate the total grass requirement for the animals

**Table 2-11: Grass requirement for animals in Bangladesh**

| Animal | Nos. in Bangladesh | Grass kg/animal/yr | Total grass (tonne per yr) |
|---|---|---|---|
| Cattle | 2,46,99,707 | 4380 | 10,81,84,717 |
| Buffalo | 15,08,022 | 6570 | 99,07,704 |
| Sheep | 37,51,529 | 365 | 13,69,308 |
| Goat | 2,67,74,314 | 355 | 95,04,882 |
| Total | 43,23,78,583 | | 12,89,66,611 |

So the total grass requirement is about 12.89 Crore tonne / year. There are four types of grasses available for animal feeding and each one has different area requirement per tonne of production. The grass production area required is given in the table below:

**Table 2-12: Grass production area**

| Name of Grass | Percentage of this grass in Bangladesh | Grass quantity in Tonne / year | Grass production - Tonnes / acre /yr | Production Area required |
|---|---|---|---|---|
| Pakchong / Nepier grass | 70% | 9,02,76,627.36 | 190 | 4,75,140.14 |
| German grass | 20% | 2,57,93,322.10 | 75 | 3,43,910.96 |
| Rye grass | 5% | 64,48,330.53 | 75 | 85,977.74 |
| Tall fescues | 5% | 64,48,330.53 | 15 | 4,29,888.70 |
| | | | | 13,34,917.55 |

However, all the grasses are not suitable for multipurpose use because of the shade tolerance limits. The shade tolerance of different grasses is given in the table below:

**Table 2-13: Shade tolerance and yield loss in different varieties of Grass**

| Name of Grass | Shade Tolerance level | Yield loss if the shade is about 50% |
|---|---|---|
| Pakchong / Nepier grass | 30% | 30 to 35% |
| German grass | 20% | significant |
| Rye grass | 20% | Significant |
| Tall fescues | 40% | 15-20 % |

So considering the above, German grass and Rye Grass areas are to be avoided. Even then about 9 Lakh acres of area is suitable for multipurpose use.

It is quite clear that the shed area (total about 27,000 acres) is very small as compared to the open area estimated above. Also, at a particular location the sheds would be very small and they will be particularly small in dairies belonging to individuals. For example a dairy having 100 cattle, the total shed area expected is 1500 sq ft which is 139.3 sqm. This would hardly give 10 to 12 kw. This is too small a size to become even a part of a grid connected facility. Moreover the strength of sheds has big variation across various farms and would require different levels of strengthening at different farms. Keeping the above in view, its clear that the shed areas will not significantly contribute to multipurpose use effort. However, the shed areas where strong enough can be used for catering to internal requirement of the farms.

The grass production areas on the other hand will definitely contribute to multipurpose use of land as these are large contiguous areas and can be treated similar to multipurpose use of land for RE with agricultural fields.

# 3.0 ANALYSIS OF RE TECHNOLOGIES

## 3.1 SOLAR PHOTOVOLTAICS

### 3.1.1 Module Technologies

All kinds of module technologies can be used for this application. Traditional modules doesnot have transparent back cover. In case of a transparent back covering, thespaces between the cells allows the light to largely passthrough and reach the plants below. Increase in light transmissionwill also help in increase in crop types which can be planted.Presently,bifacial solar PV modules are more effective which can also generate power from both sides. Based on design, the row-to-row distance tends to be higher thatwill increase the amount of light available on the reverse side of theModules. Also, the increased height of the structure (upto a limit)increases the amount of reflected light received at the back side. The Albedo of the crops underneath the panels impacts the amount of light being reflected and will play a role on the possible usage of bifacial panels. The impact of Albedo on the energy yield is being studied at National Institute of Solar Energy near Delhi and the results are expected to be published in some time.

The use of bifacial modules inmultipurpose use of land has been studied in view of the above criteria and also the cost.It is worth mentioning that the bi-facial modules are generally available in Mono PERC technology only and not Poly crystalline. The generation of a Bi-facial is better by 8% as compared to a monofacial panel.

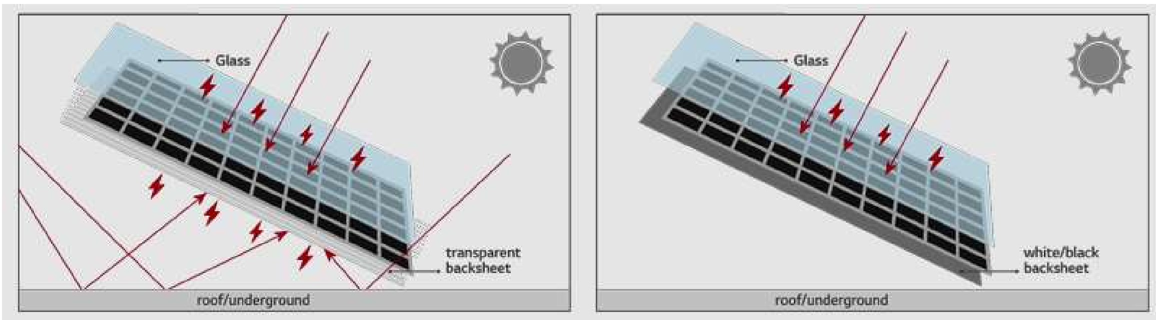



**Figure 3-1: Bifacial and Mono-Facial modules**

Organic photovoltaics (OPV) is a type of module where selective spectral adjustment of the active layers ofOPV is possible. In this case the solar spectrum can be transmitted underneath and used by crops for photosysnthesis. However, these modles are in launch phase in the market hence can be considered in future design.

### 3.1.2 Module Mounting Structure and Civil Foundation

#### 3.1.2.1 Design Aspects

Design of module mounting structure (MMS) mainly depends on the specific agriculture application or type of crop envisaged for the location. The input parameters important are the system height, wind load and the distancesbetween the steel supports. The row spacing, height of selected crop with margin and alignment along with agricultural machine usage constraints play avital role in optimized design. In case of fisheries application, floating type MMS is installed over water bodies. In case the mechanized farming is to be done then the minimum clearance for the panels from the ground needs to be 3m to 5m which allows tractors as well as harvesting machines to be operated. In case of manual farming a height of around 1.5m is to be maintained so that the farmer can get underneath the panels in sitting or bent posture.

#### 3.1.2.2 Tracking mechanism

There are basically two types of tracking, single axis and dual axis tracking. In single-axis photovoltaictracking, the modules follow the sun horizontallyaccording to the sun's angle of incidence orvertically according to the sun's azimuth (orbit). Dual-axistrackers do both,which maximizes the energy yield. However, economic viability of tracking mechanism has to be evaluated case to case as there is upfront and maintenance cost involved with these systems. Both manual seasonal tilt as well as mechanical tilting systems can be deployed along with the Agrivoltaics provided it is econimically viable. However, If the tracking system is being deployed, then care has to be taken that the minimum height reached during the tracking process should not violate the 3.5m and 1.5m for mechanized and manual farming respectively.

#### 3.1.2.3 Maintenance friendly design

The access to all location needs to be provided by an effective and friendly design. This includes walkway, stairs, piping and cable routing etc. Critical parameters to maintenance friendly design are easy access to all plant equipments including modules, strings, inverters, combiner box and piping system without much disturbance to the crops. The onine monitoring system shouldbe designed in such a way that it enables operator to monitor and identify remotely the issues and particular location of concern. The cables should be buried deep enough so that the agricultural equipment does not dig through the cables.

#### 3.1.2.4 Civil foundation and works

Anchoring or foundation is designed to ensure the statics and stability of the entire system.Structural foundations shall be optimally designed for withstanding high wind loads apart from the dead loads. Specific attention with respect to agriculture practices shall be considered in civil works. Specialized anchors and floating mechanism needs to be designed in case of fisheries application.

### 3.1.3 Water and Light Management

The design with respect to piping and flow of water from module cleaning shall be effectively planned for effective irrigation. Also in case of animal husbandary such water shall be used for cleaning purposes. Design shall be specific to agricultural crops, animal husbandary, other usage based on the application.

Based on the crop type and application the light requirement shall be optimized by designing the structural spacing etc.

## 3.2 WIND ENERGY

Multipurpose use of land with respect to wind energy is an easy implementation task. All wind parks can be used for other purposes as only the footfall of wind turbine generator (WTG) cannot be used. Balance whole area is available for multipurpose.

All technologies in wind energy systems are multipurpose friendly.

**Figure 3-2: Wind with agriculture**

# 4.0 PLANT DESIGN

# PLANT DESIGN

## 4.1 MAJOR COMPONENTS

There are three types of plants being considered under this project on multipurpose usage of land. The agricultural fields can have modified ground mounted plants. The fish ponds will have some modified floating solar and the animal farms can have rooftops in the shed area and the grazing or other open areas can have some modified ground mounted plants.

In any case, the major components in all the three cases is going to remain same as the base technology (ground mounted or rooftop or floating solar) on which improvements are done to make it suitable for multipurpose use. The components like structures, panels, inverters, cables, trackers, junction boxes transformers etc. are going to remain same. Only the technology, design, layout or specifications etc. in some of the components would change to accommodate the requirements of multipurpose use.

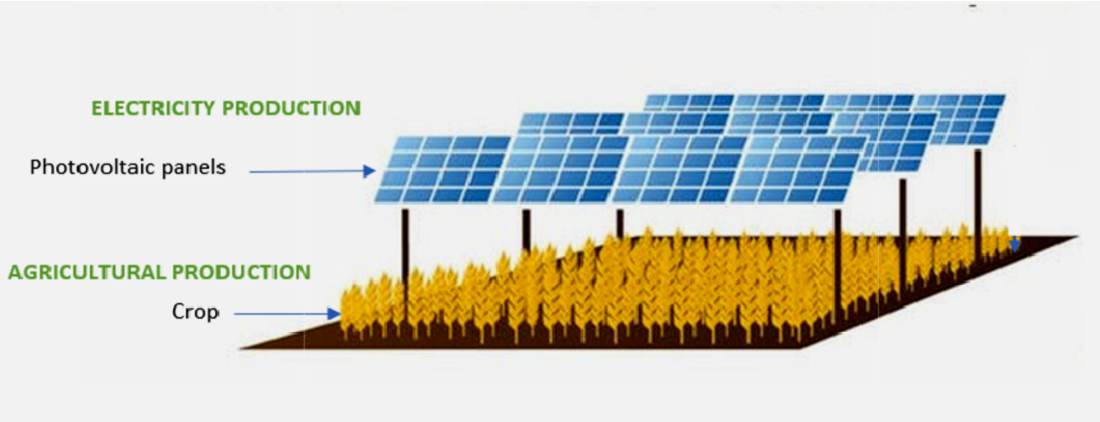



**Figure 4-1: Solar generation with agriculture**

## 4.2 CRITERIA FOR PLANT DESIGN

### 4.2.1 Approach of Design

The design of the system has three types of approach

- **Energy Centric**

In this maximizing energy output is main criteria of the design

- **Agriculture centric**

This approach concentrates on higher yield output

- **Energy and Agriculture centric approach**

In this case balanced trade-off is considered while designing the system.

In view of the food security issue, the recommendations of this exercise will be more of agricultural centric. The effort will be to have a minimal impact on the agricultural yield.

### 4.2.2 StructuralDesign

Structures shall be designed to withstand high wind loads including dead loads and also adaptive for all thermal expansion. Optimal height and spacing are important criteria for the structural design.

### 4.2.3 Reflectivity of ground (in case of bifacial module)

In case of bifacial modules, the reflective radiations also play a vital role which are higher in case of high reflective surfaces. The crops have an Albedo from .15 to 0.2.

### 4.2.4 Maximize land equivalent ratio (LER)

Land equivalent ratio is a method used for measuring the effectiveness of land utilization for the simultaneous production of crops and electricity.

$$LER = \frac{Ymul}{Yag} + \frac{Emul}{Epv}$$

Where, Ymul and Yag are yield from multipurpose land and only agriculture respectively and Emul and Epv are energy output from multipurpose use of land and only solar PV.

The LER could vary from 1.4 to 1.7. The agri centric design as being proposed for Bangladesh shall have a value of around 1.5.

### 4.2.5 Harmonic integration of solar and agriculture/other application

Photosynthesis Active Radiation (PAR) is the range of light wavelengths that is mostsuitable for photosynthesis whereas for solar power is dependent on the solar radiation and is linearly proportional to light intensity. Based on the PAR requirements, selection of crop is done to maximize the yield. Possibility of an effective use of water by multipurpose use of land is high. Based on the approach of design we follow as per section 4.2.1, the layout completely changes.

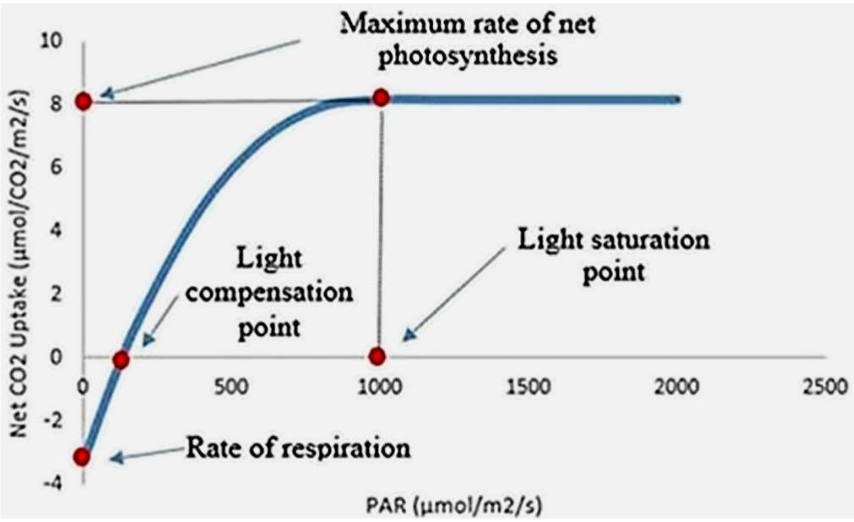


**Figure 4-2: Light response curve**

### 4.2.6 Impact on efficiency of Solar Generation

Key factors affecting efficiency are temperature, cleanliness of modules and loading of inverters etc. Due to crops the ambient temperature also reduces which improves the efficiency of Solar generation.The same is true and even better for the floating solar.

## 4.3 LAYOUT ANALYSIS

Layout of the integrated agro-energy system is effectively plotted based on the design which suits the application. Placement of different components and equipment's are based on the constraints given by application. Optimum layout varies with different approach as discussed in section 4.2.1. Since the panel rows distance will be more in agrivoltaics as compared to a normal ground mounted plant, the use of string inverters could be better to minimize the DC losses.

## 4.4 CROP MANAGEMENT

Crop management is very important aspect for higheryield and economic viabiliy. There are few important parameters which has to be considered for effective multi-purpose use of land.

### 4.4.1 Critical Parameters

#### 4.4.1.1 Shade tolerance

It is important to identify and implement shade tolerant crop and light reduction shall not affect the productivity of crop.

#### 4.4.1.2 Height of crops

Crops with lower heights have to be identified for effective use of land. The structural cost of solar PV plant increases with tall crops.

#### 4.4.1.3 Crop rotation

To preserve soil fertility and maximize the profit crops are rotated.

#### 4.4.1.4 Water management

Based on crop type effective irrigation system has to be implemented with the module cleaning water.

#### 4.4.1.5 Light management

PV covering ratio is varied based on PAR requirement.

## 4.5 O&M ASPECTS

O&M of multipurpose project shall be carried out by farmers along with technical experts for operating solar plant. The effective utilization of manpower is possible by utilizing resources in synergetic manner.

## 4.6 PLANT DESIGN FOR AGRICULTURAL FIELDS

**Figure4-3: Different application and types of multipurpose design**

The main consideration of design of PV plants in the agricultural fields is the minimal loss to the crops as it is related to the food security of the country. The aim is therefore to keep the total loss of yield in crops because of multipurpose use to 10 to 15%. Since 40% shade tolerant crops are being considered, therefore the area of fields that is shaded more than 40% is to be kept minimum after the installation of PV plants. The area that would be shaded by different elements in a solar plant would depend upon the following parameters:

- Configuration of panels – 1Portrait, 2 Portriat, 2 Landscape, 4 landscape etc.
- Pitch of the panel rows – Corresponding to different ground coverage ratios. More is the pitch, more is the light reaching the ground
- Panel Tilt – Starting from flat panels to Latitute of the site
- Height of the panels – Higher the panel, more would be the light reaching the ground from below the panels
- Azimuth – Tilt of the panel to the South
- Fixed tilt / Tracker –Tracker is likely to give more homogeneity of light

Variation of the above parameters gives several permutations and combinations and each set gives a different figure of percentage land area that has shade of less than 40%. To compute this area of less than 40% shading arising out of various permutations and combinations of the above parameters, simulation exercises were run. The following cases have been simulated using panels of 540 wp having size of 2.256m X 1.133m.

### 4.6.1 Base case for simulations

The base case comprises of the following parameter set

**Table 4-1: Base case for simulation**

| Particulars | Base Case |
|---|---|
| Configuration | 1P |
| Pitch (m) | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% |
| Panel Tilt (Degrees) | 15 |
| Height (m) | 3.75 |
| Azimuth (Degree) | 180 |

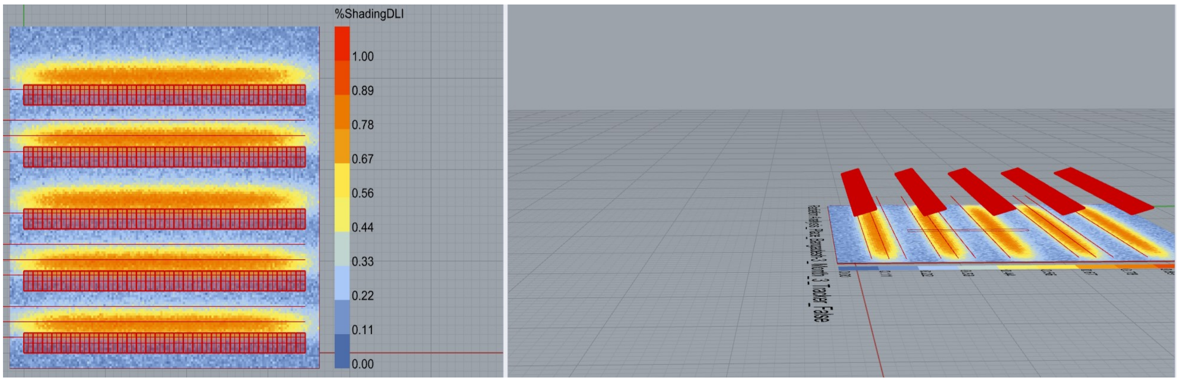



**Figure4-4: Top and Isometric View showing the area under different shading conditions**

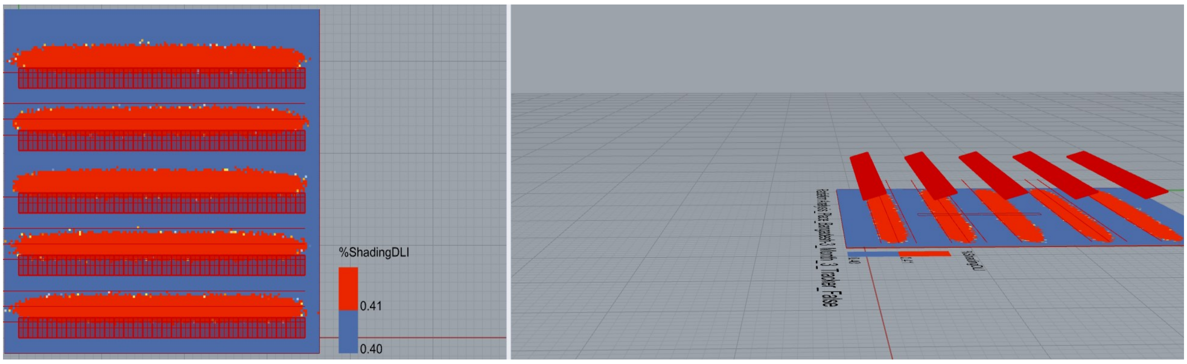



**Figure4-5: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading is 63.3%

### 4.6.2 Case 1

Case 1 is made by changing the pitch to 6.84m as compared to the base case

**Table 4-2: Case 1 for simulation**

| Particulars | Base | Case 1 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 6.84 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 33% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

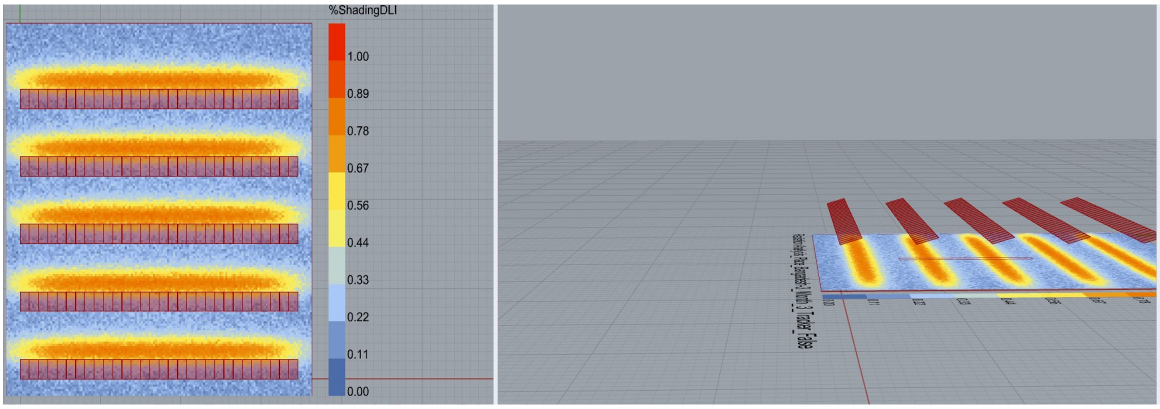



**Figure4-6: Top and Isometric View showing the area under different shading conditions**

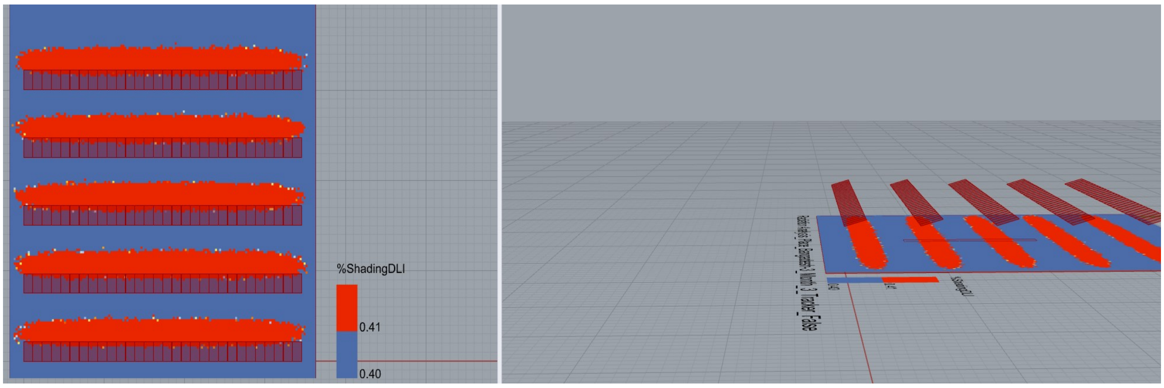



**Figure4-7: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading reduced to 61%

### 4.6.3 Case 2

Case 2 is made by changing the pitch to 5.64m as compared to the base case

**Table 4-3: Case 2 for simulation**

| Particulars | Base | Case 2 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 5.64 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 40% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

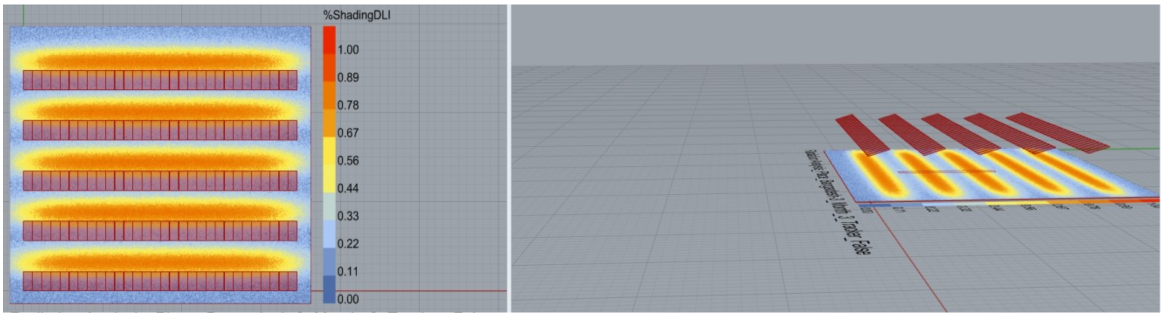



**Figure4-8: Top and Isometric View showing the area under different shading conditions**

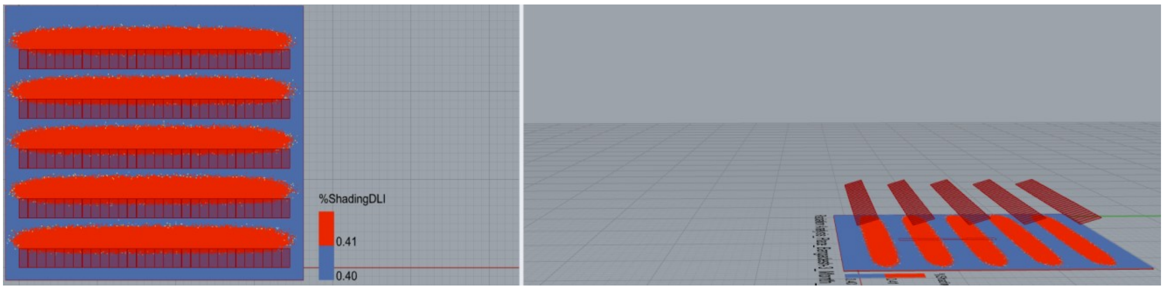



**Figure4-9: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading reduced to 50.5%

### 4.6.4 Case 3

Case 3 is made by changing the pitch to 9m as compared to the base case

**Table 4-4: Case 3 for simulation**

| Particulars | Base | Case 3 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 9.02 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 25% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

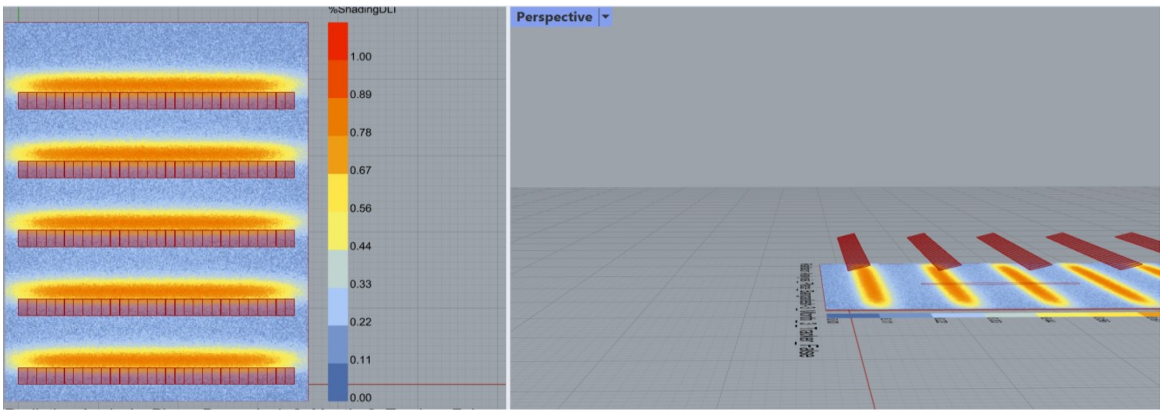



**Figure4-10:Top and Isometric View showing the area under different shading conditions**

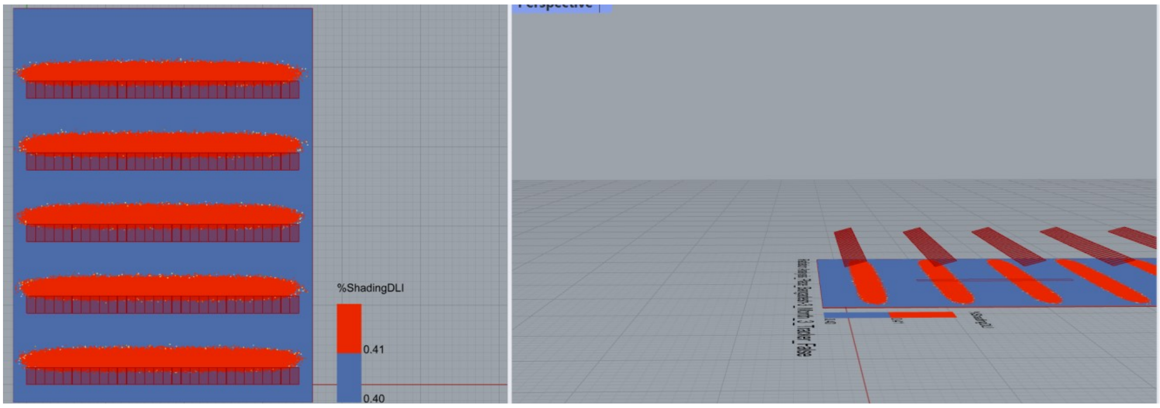



Figure4-11: Top and Isometric View showing the area below and above 40% shading

Result - Area under 40% shading increased to 73.3%

### 4.6.5 Case 4

Case 4 is made by changing the panel tilt to 4% as compared to the base case

**Table 4-5: Case 4 for simulation**

| Particulars | Base | Case 4 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage  Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 4 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

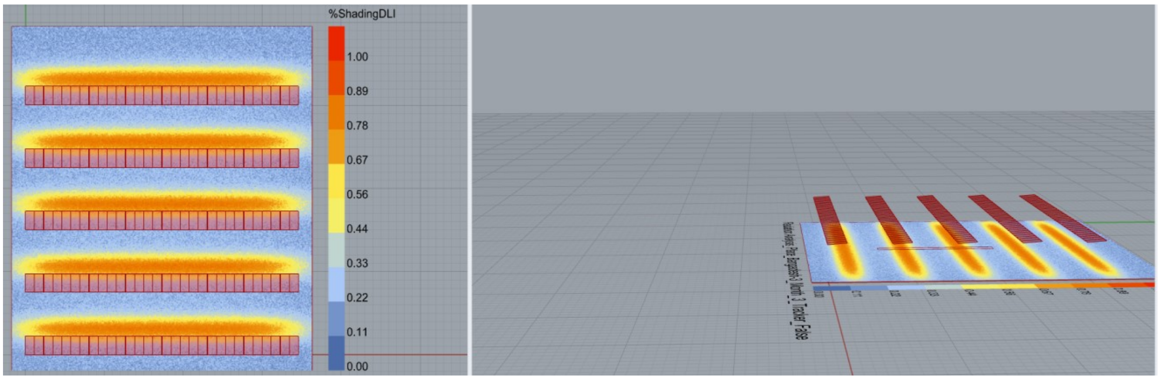



Figure4-12: Top and Isometric View showing the area under different shading conditions

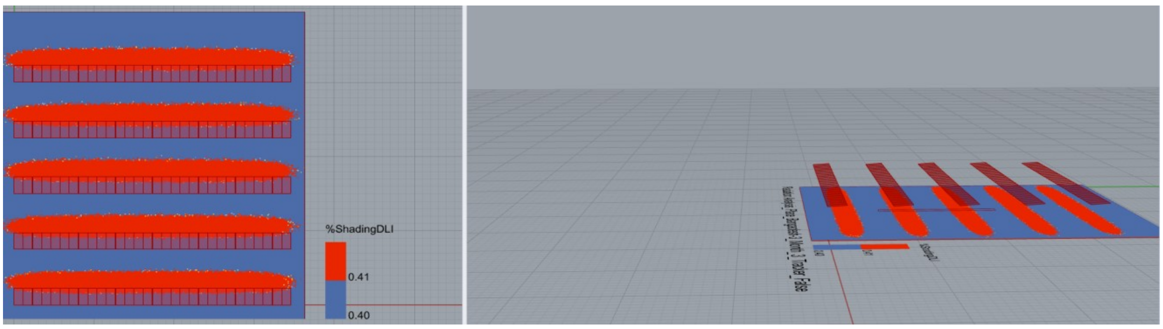



Figure4-13: Top and Isometric View showing the area below and above 40% shading

Result - Area under 40% shading 65.4%

### 4.6.6 Case 5

Case 5 is made by changing the panel tilt to 24% as compared to the base case

**Table 4-6: Case 5 for simulation**

| Particulars | Base | Case 5 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 24 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

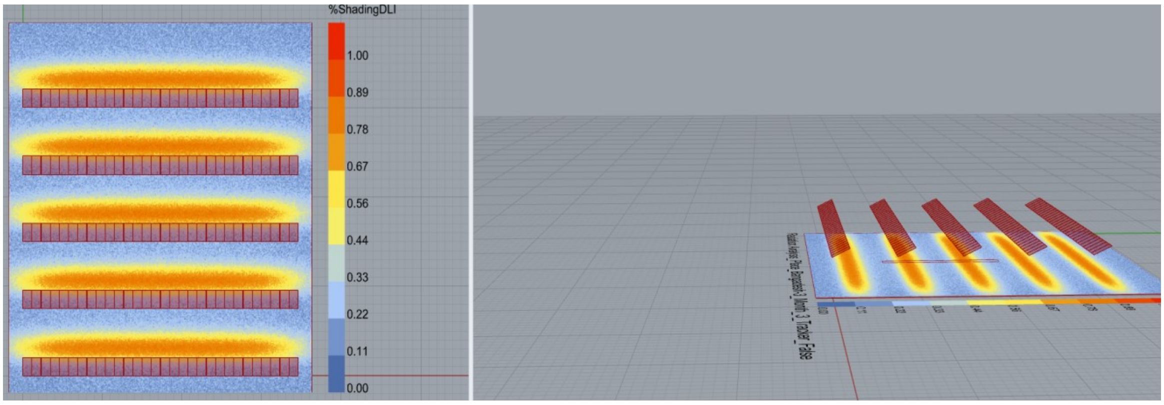



**Figure4-14: Top and Isometric View showing the area under different shading conditions**

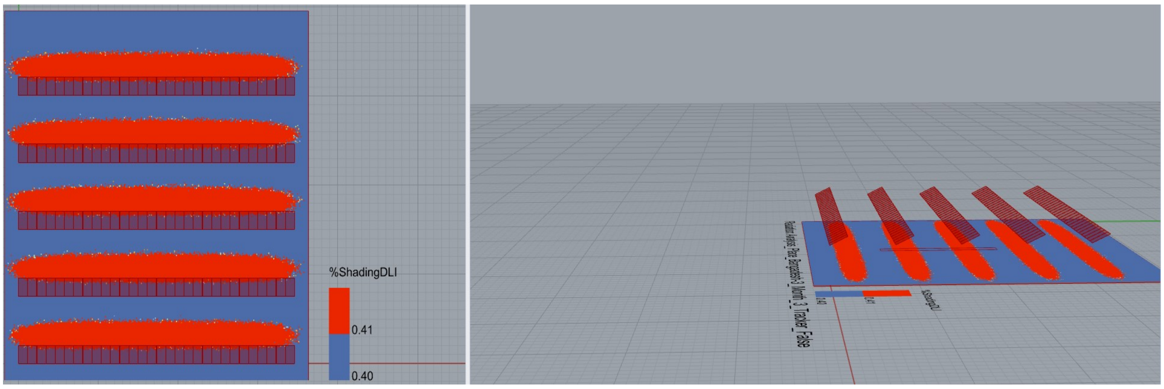



**Figure4-15: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading is 62%

### 4.6.7 Case 6

Case 6 is made by changing the system to an East West Tracker of plus minus 60 degrees as compared to the fixed tilt in the base case

**Table 4-7: Case 6 for simulation**

| Particulars | Base | Case 6 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | Tracker |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

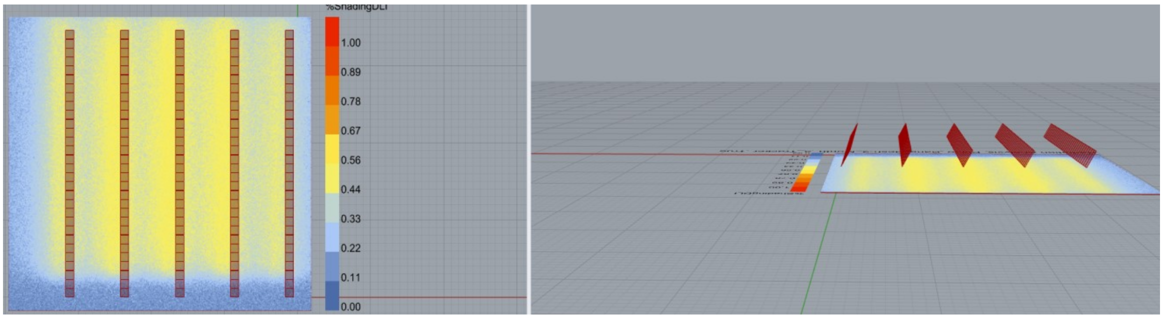



**Figure4-16: Top and Isometric View showing the area under different shading conditions**

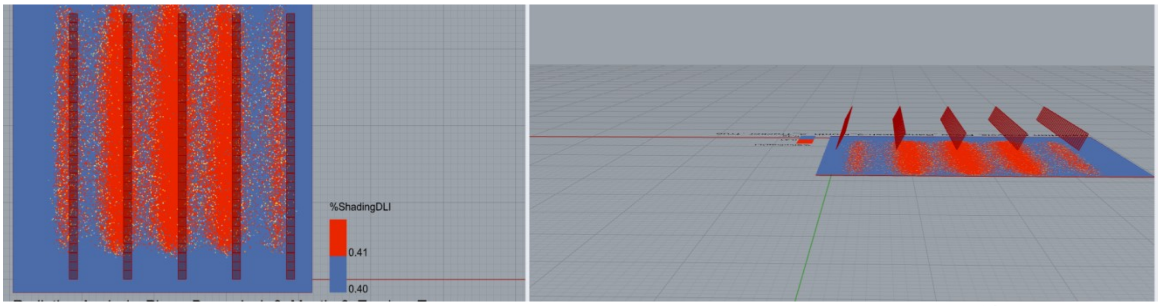



**Figure4-17: Top and Isometric View showing the area below and above 40% shading**

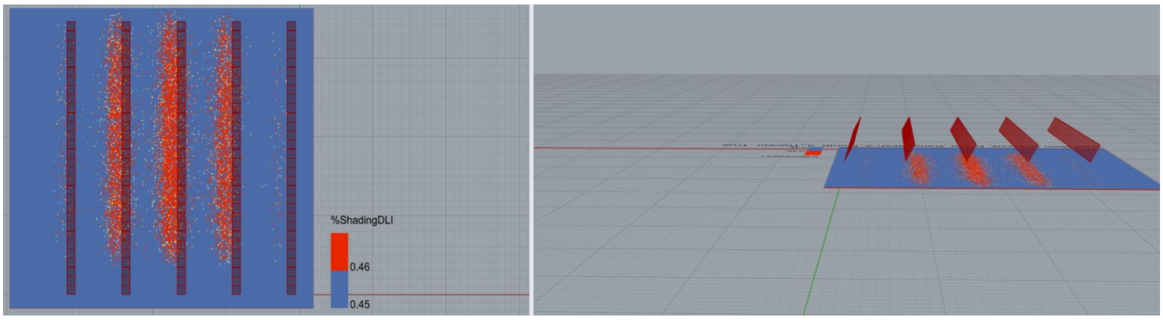



**Figure4-18: Top and Isometric View showing the area below and above 45% shading**

Result - Area under 40% shading is 35%. However it is interesting to see the total shading from 40 to 50%

**Table 4-8: Land area in different shading categories**

| Shade category | Percentage land area |
|---|---|
| Below 40% Shade | 35% |
| 40-42.5% shade | 37.5% |
| 42.5-45% shade | 27.5 |
| 45-50% shade | |

This means that 72.5% area is below 42.5% of shade.

### 4.6.8 Case 7

Case 7 is made by changing the system to an East West Tracker of plus minus 60 degrees as compared to the fixed tilt in the base case and changing the height to 5m as compared to case 6

**Table 4-9: Case 7 for simulation**

| Particulars | Base | Case 6 | Case 7 |
|---|---|---|---|
| Configuration | 1P | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% | 30% |
| Panel Tilt (Degrees) | 15 | Tracker | Tracker |
| Height (m) | 3.75 | 3.75 | 5 |
| Azimuth (Degree) | 180 | 180 | 180 |

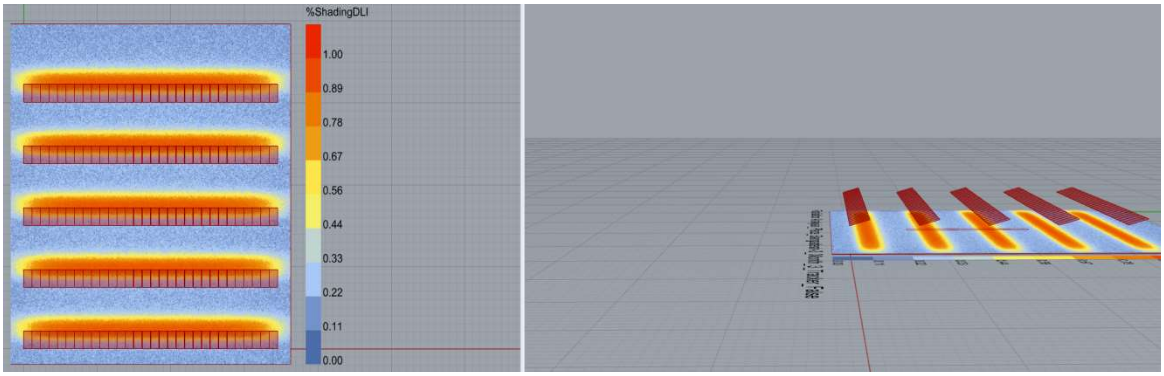



**Figure4-19: Top and Isometric View showing the area under different shading conditions**

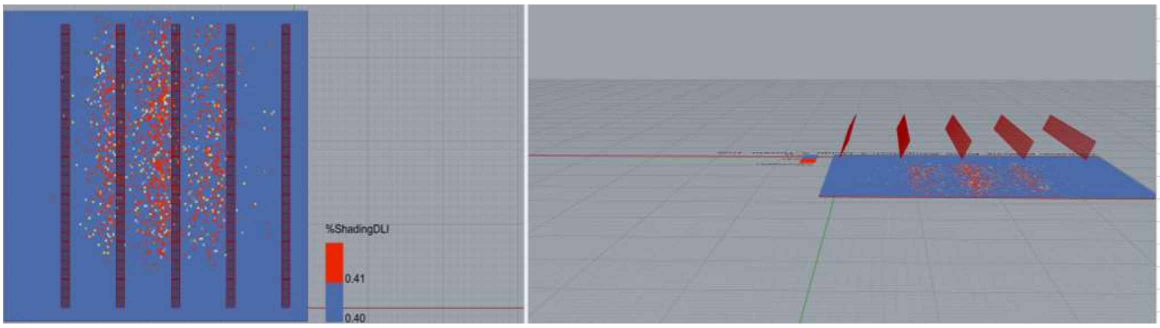



**Figure4-20: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading is 80.5% and balance 19.5% is between 40 and 50%.

### 4.6.9 Case 8

Case 8 is made by changing the minimum panel ground clearance to 2.5m as compared to the base case.

**Table 4-10: Case 8 for simulation**

| Particulars | Base | Case 8 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |

| Particulars | Base | Case 8 |
|---|---|---|
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 2.5 |
| Azimuth (Degree) | 180 | 180 |

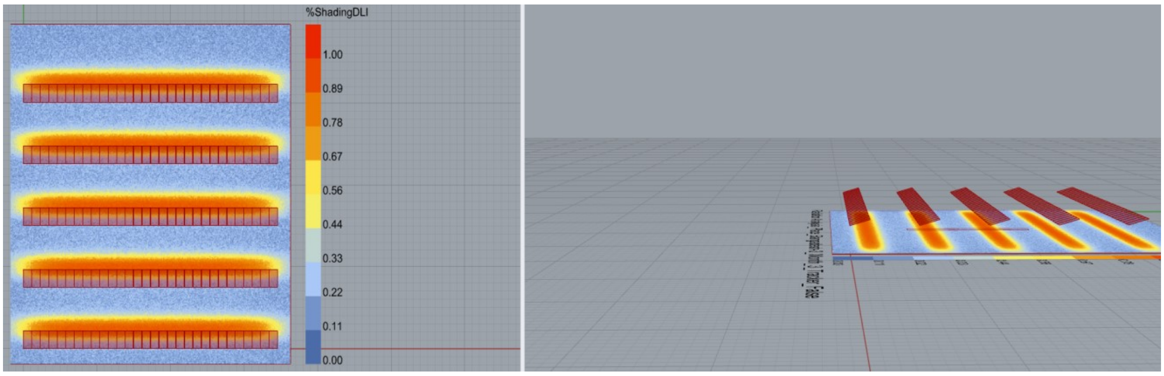


**Figure4-21: Top and Isometric View showing the area under different shading conditions**

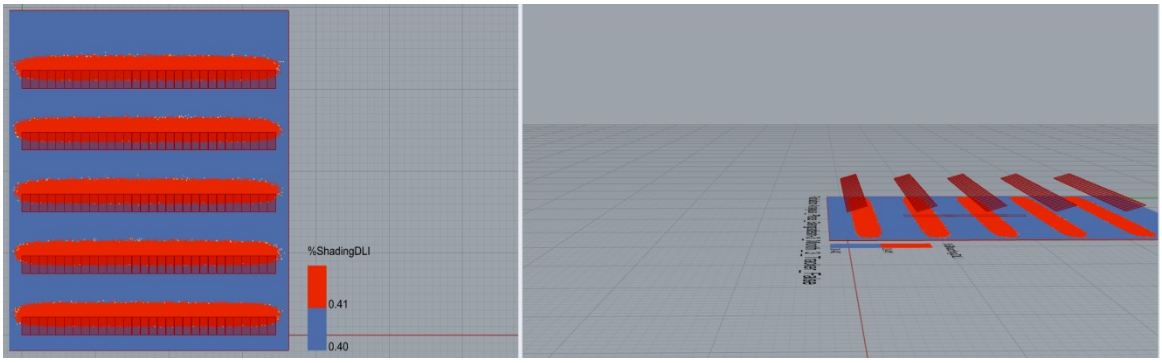



**Figure4-22: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading reduced to 61.7%

### 4.6.10 Case 9

Case 9 is made by changing the minimum panel ground clearance to 5m as compared to the base case.

**Table 4-11: Case 9 for simulation**

| Particulars | Base | Case 9 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 5.0 |
| Azimuth (Degree) | 180 | 180 |

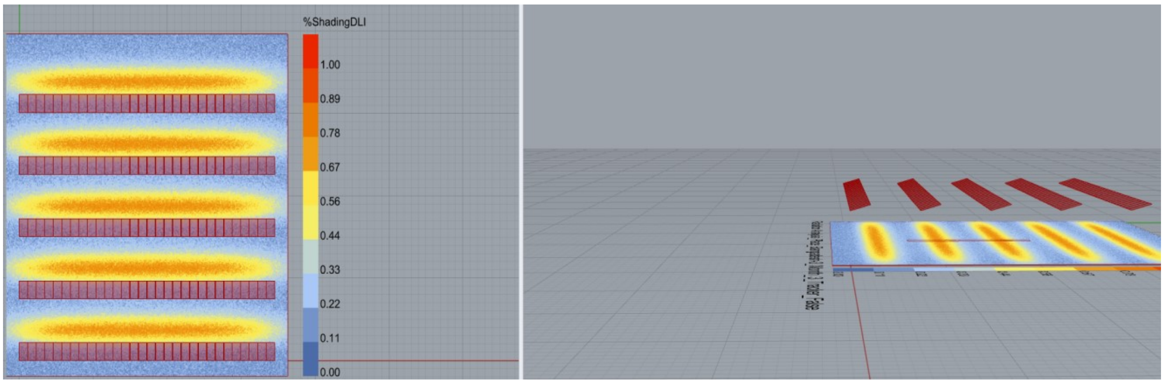



**Figure4-23: Top and Isometric View showing the area under different shading conditions**

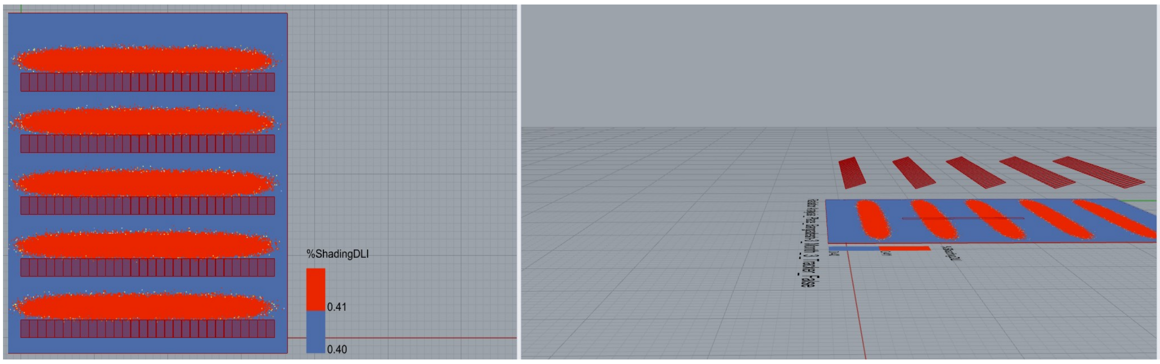



**Figure4-24: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading increased to 66.7%

### 4.6.11 Case 10

Case 10 is made by changing the Azimuth angle to 160 degree as compared to the base case.

**Table 4-12: Case 10 for simulation**

| Particulars | Base | Case 10 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 160 |

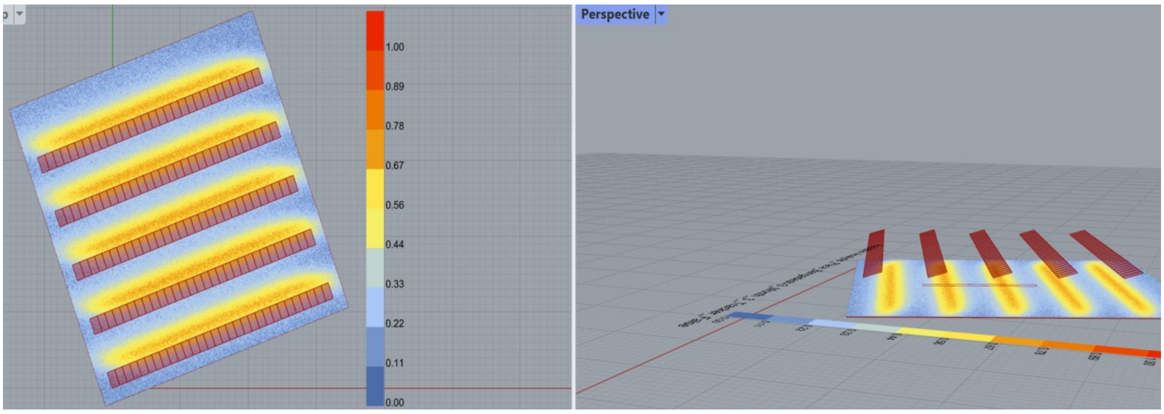



**Figure4-25: Top and Isometric View showing the area under different shading conditions**

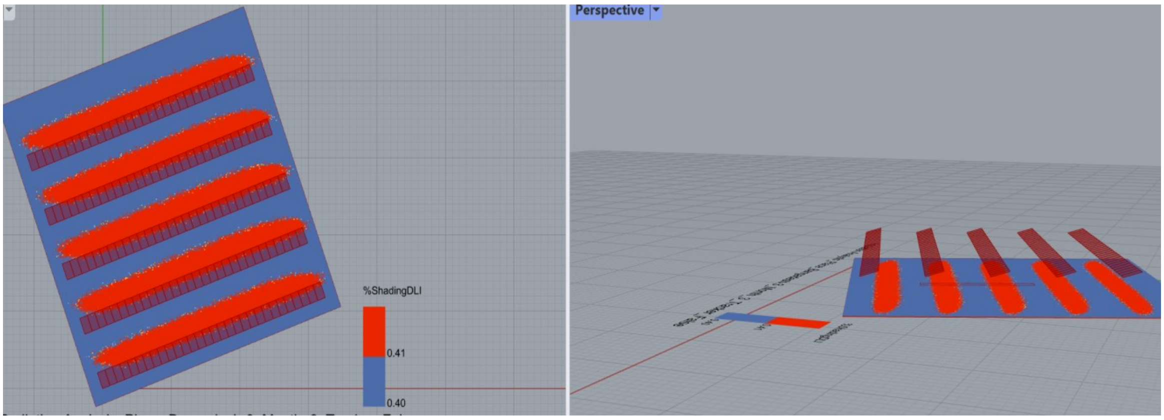



**Figure4-26: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading increased to 65%

### 4.6.12 Case 11

Case 11 is made by changing the Azimuth angle to 170 degree as compared to the base case.

**Table 4-13: Case 11 for simulation**

| Particulars | Base | Case 10 |
|---|---|---|
| Configuration | 1P | 1P |
| Pitch (m) | 7.52 | 7.52 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 170 |

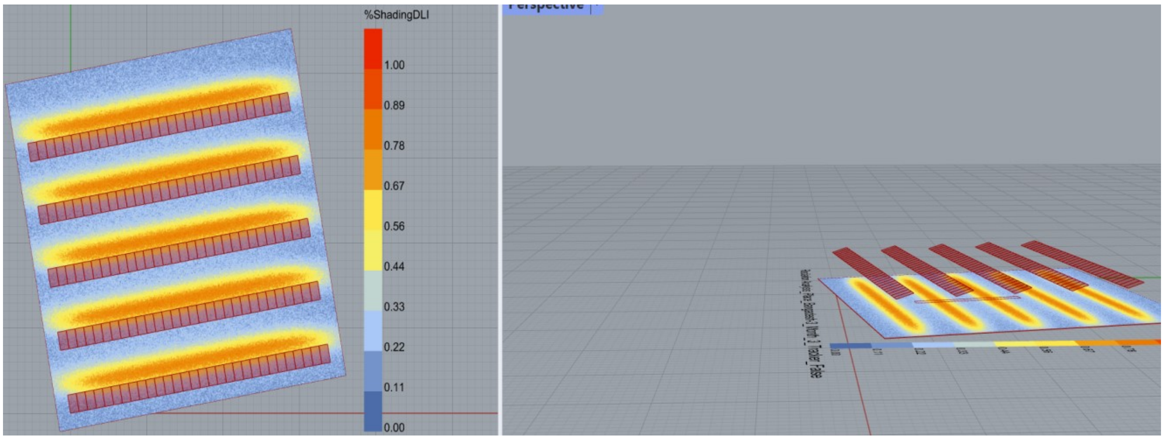



**Figure4-27:Top and Isometric View showing the area under different shading conditions**

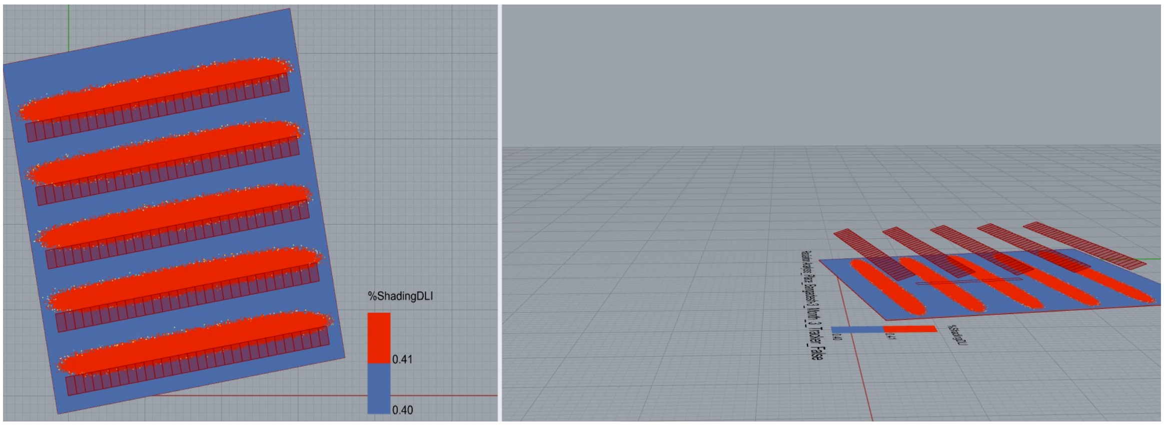



**Figure4-28: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading increased to 63.3%

### 4.6.13 Case 12

Case 12 is made by changing the panel configuration to 2P as compared to the base case. Since the panel configuration changed the pitch has been accordingly doubled as compared to the base case.

**Table 4-14: Case 12 for simulation**

| Particulars | Base | Case 11 |
|---|---|---|
| Configuration | 1P | 2P |
| Pitch (m) | 7.52 | 15.04 |
| Ground coverage Ratio (Computed from Pitch) | 30% | 30% |
| Panel Tilt (Degrees) | 15 | 15 |
| Height (m) | 3.75 | 3.75 |
| Azimuth (Degree) | 180 | 180 |

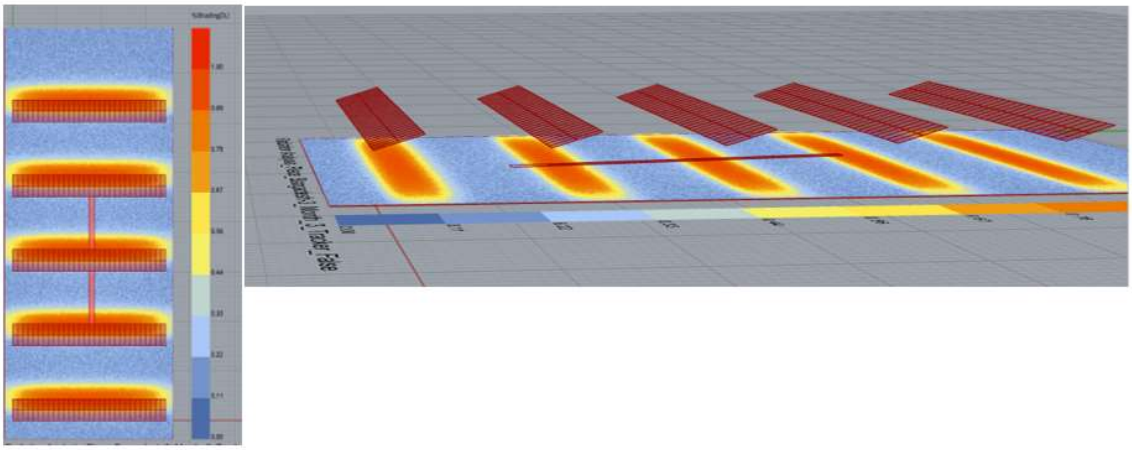


**Figure4-29: Top and Isometric View showing the area under different shading conditions**

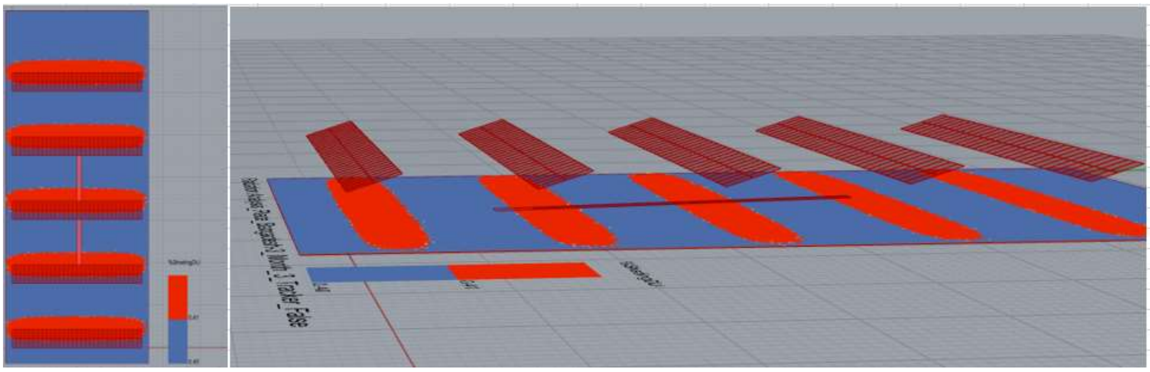


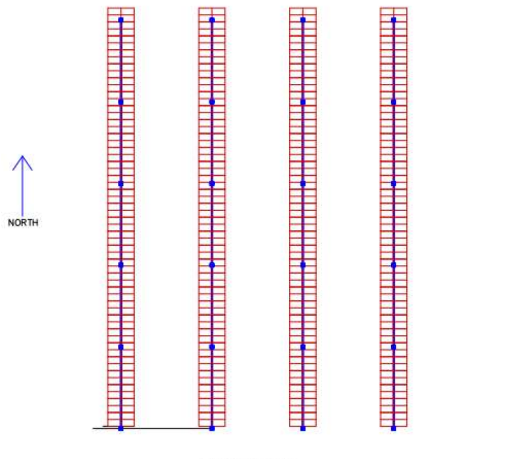
**Figure4-30: Top and Isometric View showing the area below and above 40% shading**

Result - Area under 40% shading increased to 64.3%

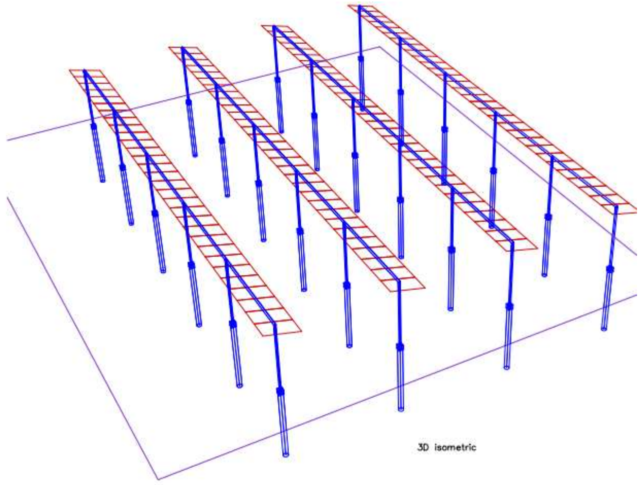
From the above simulation results, Case 7 i.e. trackers at a height of 5m with a pitch of 7.52m is giving the best results in which the yield loss of agriculture is expected to be below 10%. It is therefore the recommended design.

The overall design for this case would like this

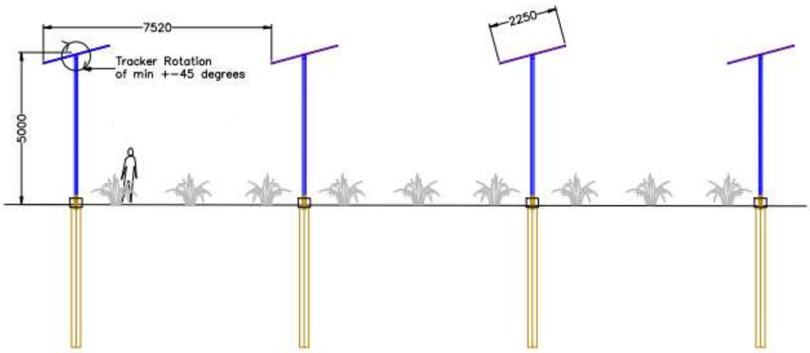
Figure XX – General arrangement for the recommended design




Top View of Tracker



3D isometric




Section View of Tracker

## 4.7 PLANT DESIGN FOR FISH PONDS

### 4.7.1 Fish catching technique in commercial fish farms

In the fish ponds generally, the fish is caught by holding the net across the width of the pond and walking from one end to the other along the length of the pond as shown in the pictures below:

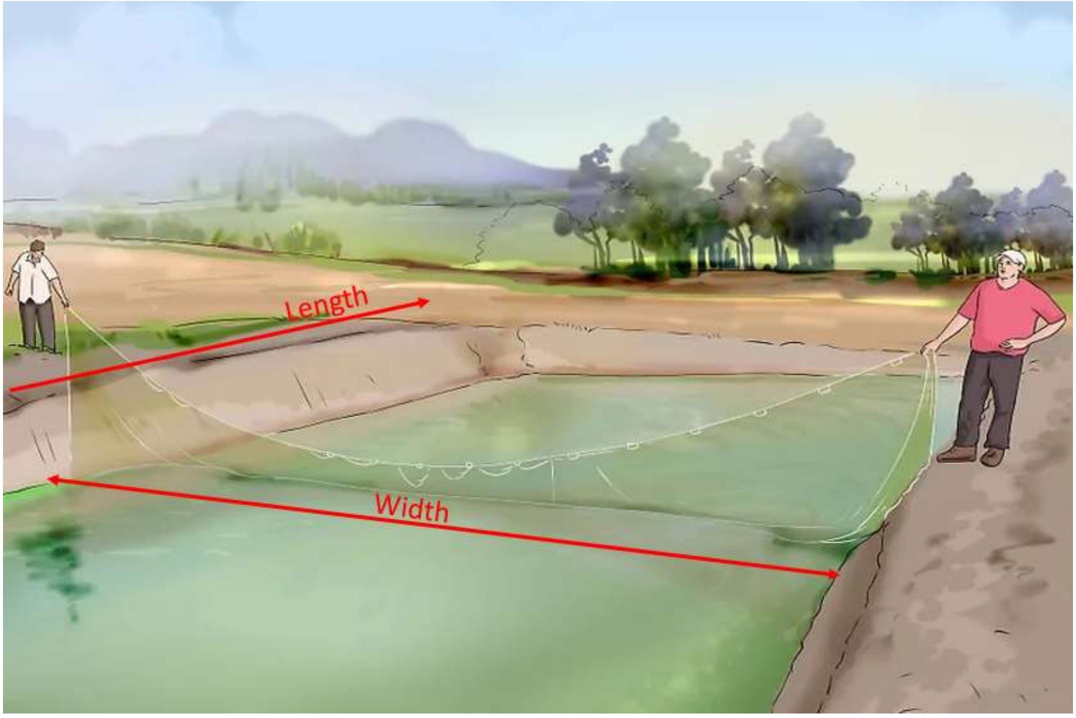



**Figure4-31: Fish catching technique in commercial fish farms**

**Figure4-32: Fish catching technique in commercial fish farms**

### 4.7.2 Proposed design for putting solar in a commercial fish pond

The ponds' depth keeps varying in the rainy and dry season. The areas along the banks have to be left without solar panels as they are likely to get shaded by the banks when the water level goes down in the dry season. This area to be kept vacant on each side of the pond should be around 1.5 times the depth of the pond (maximum depth that comes in the dry season). This is to avoid the shading from the sides.

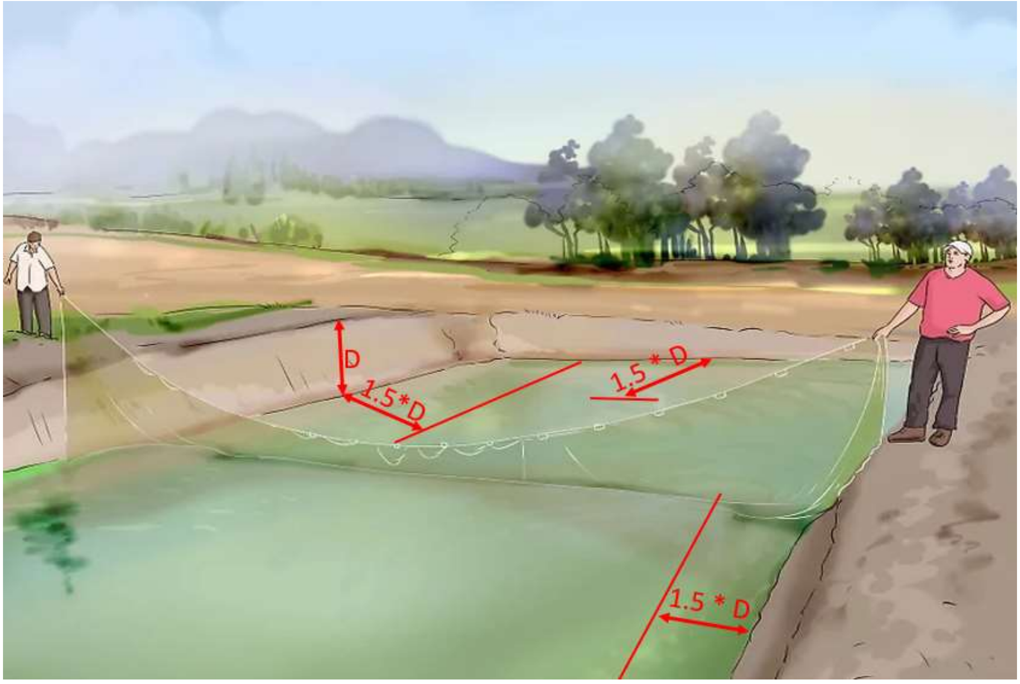



**Figure4-33: The 50% area of the pond along the length is to be kept vacant for the fish catching operation.**

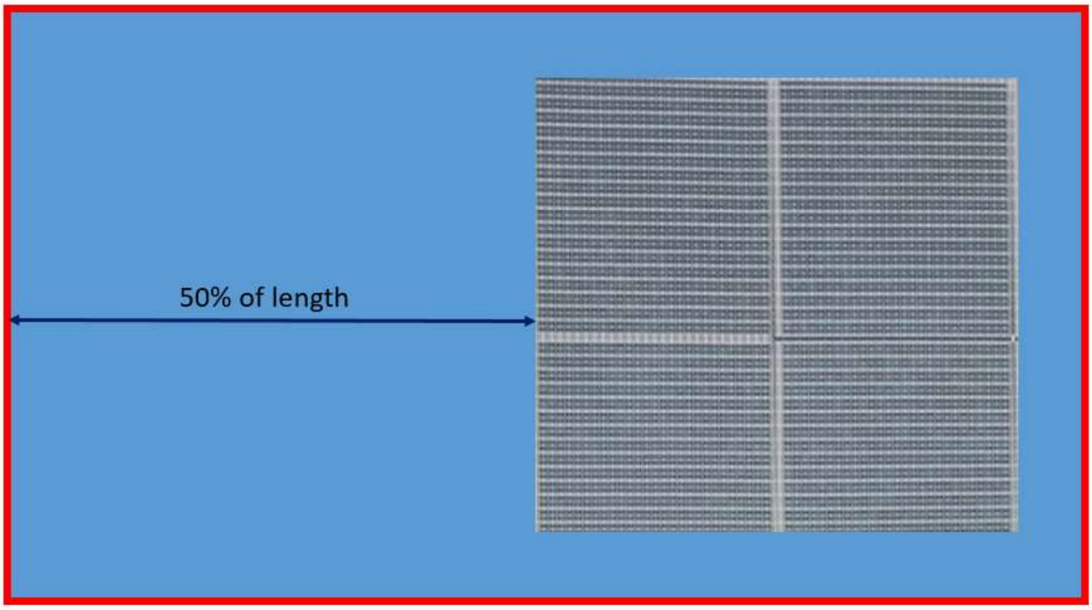



**Figure4-34: The pond area can be used for putting solar**

With the above configuration, about 40% of the pond area can be used for putting solar. On this basis the overall potential of multipurpose use, the plant design and the costing has been developed.

# 5.0 DEVELOPMENT OF BUSINESS MODEL

## 5.1 TYPES OF BUSINESS MODEL

The business models discussed below are based on following premises:

- The minumum generation considered from solar power plant at a single patch of land of 1.5 acres is 350 kWp.
- Government will provide subsidies / increased tarrifs in PPAs to encourage multipurpose land use solar power plants.
- These multipurpose land use solar power plants are 'Must Run' plants.

### 5.1.1 Model-1

**Farmer - Land Owner**

**Developer - Tenant**

In this business model the land consists of number of small patches of land from small farmers that will make a large piece of land, big enough to construct about 5 MW of solar power plant. Developer will lease the land from small farmers who will pay the land rent and construct the solar power plant. Keeping food security in mind the loss of yield of crops owing to shade casted by panels shall be capped at 10%. The yield loss to farmers will be duly compensated by the Developer in the form of lease amount. To assess the lease amount a mechanism will be devised that will be just adequate to meet the yield loss.

The model will work on following stipulations:

1. The minimum lease period will be 20 years but the desirable period shall be 25 years

2. Advantages to Farmer
   - A regular income from developer in the form of rent which will compensate his loss due to reduced yield. However, this income should be only marginally above the yield loss and other incidental losses to the farmer. In no case the income should be large enough which can make a farmer forget about his basic trade i.e. agriculture and be dependent on the lease income.
   - Less water evaporation owing to panel shade
   - Power at Doorstep for irrigation purposes
   - Protection to crop from strong winds due to barrier created by solar panels and structures
   - Area Lighting will enhance the crop monitoring at night during harvesting season

3. Disadvantages to Farmer
   - Yield loss year-on-year owing to solar panel shade
   - Additional yield loss every year during annual maintenance of solar plant as well as losses due to regular maintenance of the plant in case of cable digging etc.

- Onetime yield loss during construction phase of the plant
- Only ‘shade tolerant’ crop can be sown.

4. Risks to Farmer
   - Chances of electrocution in case of poorly constructed plant or not following the instructions of the developer.
   - Falling panels, structures etc.(chances are very rare) may damage the crop and cause injury

5. Advantages to Developer
   - Differential benefit from lease expenditure to compensatory expenses to farmer
   - Plant being good candidate under ‘merit order’ rating owing to socio-economic benefits to society; power sale will not be a problem

6. Disadvantages to Developer
   - Cost of construction will increase due to increase in structure height and cable length.
   - If the project is of ‘distributed generation’ nature (number of small capacity plants are constructed in patches of land and combined power is pooled to form a large capacity plant) the cost of power integration and pooling increases.
   - On account of above factors, the cost of generation will increase

7. Risks to Developer
   - Chances of damage to cable and equipment increases owing to trespassing
   - Nuisance arising out of conflict, if any, between farmer and the developer for the entire life of project

#### 5.1.1.1 Analysis of Model-1

The model has mixed bag of pros and cons for both farmer and developer but the best part is that the income of farmer is not dwindling as he is properly compensated by the developer. Though the investment required from Developer will be more as compared to stand alone solar power plants but his interest can be safeguarded by providing adequate subsidy / increased tariff. The risk involved can be mitigated by proper execution and better selection of equipment. This model is suitable for small farmers.

### 5.1.2 Model-2

**Farmer - Land and Plant Owner**

This model is meant for farmers / farming companies / cooperative of farmerswho own and are doing agriculture on large parcels of land.If such an entity plans to get into solar business, they will have to start a subsidiary for Solar business having a separate accounting.

The model will work on following stipulations:

1. Advantages

The other advantage as compared to Model-1 will be:

- Additional source of income from solar power plant.

2. Disadvantages

In addition to Model-1, the disadvantages will be:

- Lack of adequate knowledge for the farmer to operate and maintain the plant
- Huge Investment will be required to construct, operate and maintain the plant

3. Risks

- Returns from solar power plant may not be consistent during initial years
- The loss of yield may be more than the additional income generated by the solar plant

#### 5.1.2.1 Analysis of Model-2

The model is similar to model-1 the only difference is that farmer or the farming company is the land owner as well as the developer of the solar plant. Advantages, disadvantages and the risks are similar to model-1. Since the investment will be more only big farmers or a co-operative of farmers can work on this model.

### 5.1.3 Model-3

**Developer - Land and Solar Plant Owner**

The model is meant for the solar development companies who are likely to setup plants in future but would be willing to do some agriculture in lieu of some additional tariff or other benefits from the Government.

The model will work on following stipulations:

1. Advantages

The other advantage as compared to Model-1 will be:

- Farming and solar power plant operation can be synchronised.
- Since loss of solar income would be compensated there will be no loss to the company.

- The two entities being part of one company, there will be total control on the farming and solar plant operations and the risk is lower.

2. Disadvantages

In addition to Model-1, the disadvantages will be:

- None

3. Risks

- None

#### 5.1.2.2 Analysis of Model-2

The model appears to be more suitedto a group of companies who can have full control on the farming and plant operation without any conflict between them.

## 5.2 COST AND COMPENSATION FLOW

The major cost and compensation among various stakeholdersfor model-1 will be as under:

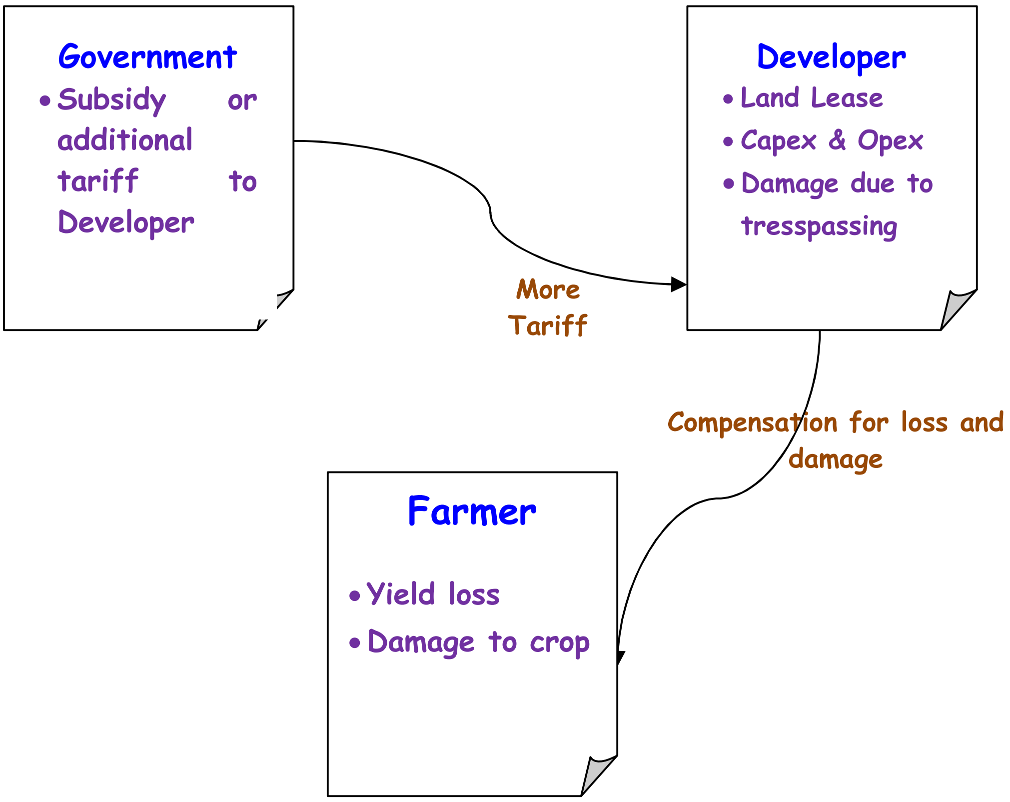



**Figure 5-1: Cost and Compensation Flow**

## 5.3 ECONOMIC ASPECTS

Compared to conventional ground mounted PV the cost for mounting of structures, site preparation and installation as well as for the cleaning and water management system significantly increases the CAPEX and OPEX.

# 6.0 REVIEW OF PPA

## 6. 1 REVIEW OF PPA / IA / LLA DOCUMENTS

The PPA for various models of multipurpose use of land for renewable energy plantswill address the following aspects:

Depending upon the three Models already discussed in the report namely:
**Model-1**
Farmer – Land Owner
Developer – Tenant

**Model-2**
Farmer – Land Owner and Developer

**Model-3**
Developer - Land and Solar Plant Owner
Subsidiary of Developer-Farming agency

The PPA, IA and LLA will need certain modifications

### Power Purchase Agreement (PPA)

The standard PPA clauses are:

- Scope of Contract
- Purchase of Energy
- Terms, Defaults and Remedies
- Covenants, Representation and Warranties
- Permits and Licenses, Approval
- Testing and Capacity Rating
- LD payable by company
- Electrical Interconnection
- Metering, Billing and Payments
- Insurance, Liability and Indemnification
- Force Majeure
- Taxes& Claims
- Environmental Regulation
- Choice of Law
- Resolution of Dispute etc.

## Suggested modifications in PPA

- A clause on Compensation to Farmer in case of Model-1 and 3 for the yield loss must be duly inserted.
- Obligations of Farmer, Developer and power procurer must be added for all the Models
- Resolution of Dispute must include the adequate redressal of conflict between Farmer and Developer for Model-1 and 3
- Safety and Security of both the parties of Model-1 and 3 must be duly safeguarded
- A mechanism should be in place to bring down the cost of generation of the developer
- Generation being distributed in nature the Electrical Interconnection clause needs to be modified.

## Implementation Agreement (IA)

The Standard IA clauses are:

- Term
- GoB Authorization
- Site acquisition
- Construction
- Operation
- Liability, Indemnification, Insurance
- Import Controls
- Bank accounts
- Foreign exchange
- Assignments & security
- Restriction on acquisition & transfer of shares or, Assets
- Force Majeure
- Taxation & Custom duties Termination
- Choice of Law
- Resolution of Disputes
- Guarantee

## Suggested modifications in IA

- The clauses like Site acquisition, Construction, Operation, Liability, Indemnification and Insurance, Security and Resolution of Disputes need to be remodelled for meeting the requirements of Model-1, 2 and 3 above.

## Land Lease Agreement (LLA)

The Standard LLA clauses are:

- Term
- Obligation of company & BPDB
- Representatives, Covenants and Warranties
- Liability and Indemnification
- Assignment and Security
- Termination
- Resolution of Disputes

## Suggested modifications in IA

- The land lease clause needs to be inserted meeting the requirements of all the Models.
- Clauses like Obligations of all the stakeholders must be included
- Clauses like Liability and Indemnification, Security and Resolution of Disputes need to be rewritten to mitigate the risks and safeguarding the interests of the various stakeholders.
- Suitable clause needs to be added for leasing the number of parcels of land by a single developer.

# 7.0 FINANCIAL AND ECONOMIC ANALYSIS

# FINANCIAL AND ECONOMIC ANALYSIS

Based on the various business models discussed in chapter-5, a detailed financial and economic analysis has been carried out.

## 7.1 ASSUMPTIONS AND ANALYSIS FOR MULTIPURPOSE USE OF AGRICULTURAL FIELDS

For making financial calculations, a detailed financial model has been developed. Like any other financial model, this model also uses assumptions like Capex, Opex, generation etc. and produces the results like Project IRR and Equity IRR etc.

For feeding in the financial model, there are two sets of assumptions. One set is a set of fixed assumptions that do not change for various scenarios. While the second set of assumptions is variable that varyin different scenarios.

There are four scenarios that have been considered. The first is the base case in which a solar Company is doing only Solar business (No multipurpose use) on a standard ground mounted and grid connected system. This Base case gives a certain project IRR and Equity IRR. Further, the financial model is run for three different Business models of multipurpose use as described in the chapter of business models. The variable parameters in a particular business model are fed in the financial model and the tariff is varied till the time it gives the same IRR as the base case and that tariff is proposed for the particular business model.

**Table 7-1: – Fixed Assumptions for base case and all business models**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1$^{st}$ year<br>0.8% per year from 2$^{nd}$ to 20$^{th}$ year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |

**Table 7-2: – Variable assumptions and result for Base case (Company doing only Solar business on a standard ground mount system)**

| | |
|---|---|
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 10,00,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWh |

### 7.1.1 Business Model-1

This model pertains to a solar development company taking land on lease from farmers.

**Table 7-3: – Variable assumptions and result for Business model 1**

| | |
|---|---|
| Solar modules | Mono PERC – Bi facial |
| Structure height | 5m |
| Module tilt | Single Axis Tracking |
| Capex | Plus 30% as compared to Base case |
| Opex | Same as base case |
| Specific generation (Average) | Plus 25% as compared to Base case |
| Land required Acre/MWp | 4.6 |
| Land lease cost (Average) paid by solar company to farmers to cover their agricultural loss and some incentive | 18,000 Taka/acre/yr. |
| Agricultural Revenue | 4.5 Lakh Taka /Acre |
| Agricultural Expenses including lease | 4.0 Lakh Taka /Acre |
| Levelized Tariff giving the same IRR as base case (for solar company) | 0.11 USD Cents /kWh |

Analysis – In this business mode l(as compared to the base case) the land required per MWp of Solar as well as Capex are increasing, that increase the Tariff. Since the generation is also increasing as compared to the base case which is balancing this increase hence the expected Tariff shall be the same as the base case to achieve similar IRR as the base case.

### 7.1.2 Business Model-2

This model pertains to an established agricultural company getting into Solar power generation. The company would setup a subsidiary company for solar project development to whom, it would lease the land. The basic structure is the same as in model 1, the only difference is that a solar development company in this case is leasing land from its own parent company rather than other farmers as in model 1. The dynamics of this model are similar to model 1 and hence the result is also the same.

### 7.1.3 Business Model-3

This model pertains to a solar development company proposing to develop a new farm with Solar plus agriculture

**Table 7-4: – Variable assumptions for Business model 3**

| | |
|---|---|
| Solar modules | Mono PERC – Bi facial |
| Structure height | 5m |
| Module tilt | Single Axis Tracking |
| Capex | Plus 30% as compared to Base case |
| Opex | Same as base case |
| Specific generation (Average) | Plus 25% as compared to Base case |
| Land required Acre/MWp | 4.6 |
| Land lease cost (Average) for solar | 50,000 Taka /acre |
| Agricultural Revenue | 4.5 lakh Taka /Acre |
| Agricultural Expenses including lease | 4.0 Lakh Taka /Acre |
| Levelized Tariff giving the same IRR as for basic agriculture trade | 0.128 USD Cents /kWh |

Analysis - Since solar is a high margin business, utilizing their land for agriculture reduces the IRR and hence a higher tariff would be required to get an IRR equal to the base case.

It is also possible that the solar development company setups an agricultural subsidiary and leases land to it for doing agriculture. In that case the dynamics will become similar to the first two models and extra tariff can be avoided but practically Solar development companies will have limited interest in such proposals.

## 7.2 ASSUMPTIONS AND ANALYSIS FOR MULTIPURPOSE USE OF FISH FARMS

The methodology for model development and calculation of proposed tariff for commercial fish farms that are being considered for the multipurpose use with RE, is same as the methodology as explained above for the multipurpose use of Agricultural farms.

In this case, there are three scenarios that have been considered. The first is the base case which is a solar Company doing only Solar business (multipurpose use) on a standard ground mount system. Further, the financial model is run for two different Business models.The details are given below:

**Table 7-5: – Fixed Assumptions for base case and all business models**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1st year<br>0.8% per year from 2nd to 20th year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |

**Table 7-6: – Variable assumptions and result for Base case (Company doing only Solar business on a standard ground mount system)**

| | |
|---|---|
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 100,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWh |

### 7.2.1 Business Model-1

This model pertains to a solar development company taking land on lease from fish farms

**Table 7-7: – Variable assumptions and result for Business model 1**

| | |
|---|---|
| Solar modules | Same as base case |
| Structure | Floating solar |
| Module tilt | 11 Degree |
| Capex | Plus 25% as compared to Base case |
| Opex | Same as the base case |
| Specific generation (Average) | Plus 2.5% as compared to Base case |
| Land required Acre/MWp | 6.6 |
| Land lease cost (Average) paid by solar company to farmers to cover their agricultural loss and some incentive | 30,000 Taka/acre/yr |

| | |
|---|---|
| Fishing Revenue | 7 Lakh Taka /Acre |
| Fishng Expenses including lease | 5 Lakh Taka /Acre |
| Levelized Tariff giving the same IRR as base case (for solar company) | 0.131 USD Cents /kWh |

Analysis – In this business model, the land required per MW of Solar as well as Capex are increasing that increase the Tariff. However, unlike the case of Agrivoltaics (where there was a good enough gain in generation to balance this increasing tariff), the gain in generation here is marginal. Hence a good 0.021 USD cents per kwh increase in tariff is required as compared to the base case if the Base case IRR is to be achieved.

### 7.2.2 Business Model-2

This model pertains to an established and large fish farming company getting into Solar generation. The company would setup a subsidiary company for solar project development to whom it would lease the space. The basic structure is the same as in model 1, the only difference is that a solar development company in this case is leasing land from its own parent company rather than other fish farms as in model 1. The dynamics of this model are similar to model 1 and hence the result is also the same.

## 7.3 ASSUMPTIONS AND ANALYSIS FOR MULTIPURPOSE USE OF ANIMAL FARMS

As explained in an earlier section, the Animal farms have two possible areas, i.e. shed area and the Grass production area for solar installation. As also explained, the shed area is not suitable for large grid connected capacity. This section therefore explains the financial analysis as done for the grass production area which is quite similar to the Agricultural fields. Despite the similarity, the numbers could be different as the Grass has a shade tolerance of only 30% as compared to vegetables that hada shade tolerance of 40%. Also, the grass is much more profitable business than vegetable production. The methodology of financial analysis as well as business models are the same as considered for the multipurpose use of agricultural land with RE.

**Table 7-8: – Fixed Assumptions for base case and all business models**

| Particulars | Assumptions |
|---|---|
| Debt : Equity | 75:25 |
| PPA period | 20 years |
| Degradation of solar modules | 2.5% - 1$^{st}$ year<br>0.8% per year from 2$^{nd}$ to 20$^{th}$ year |
| AC:DC ratio | 1:1.4 |
| BDT/USD Exchange Rate | 104 |
| Interest rate on debt | 7% |
| Loan Tenure (from financial closure) | 15 years |
| Grace period | 2 years |

| Particulars | Assumptions |
|---|---|
| Corporate tax rate | 35% |
| Tax holiday on Solar projects | 20 years |

**Table 7-9: – Variable assumptions and result for Base case (Company doing only Solar business on a standard ground mount system)**

| | |
|---|---|
| Solar modules | Mono crystalline – Mono facial |
| Structure height | Minimum ground clearance – 500mm |
| Module tilt | 15 Degree – Fixed tilt |
| Capex | 100,00,000 BDT per MWp |
| Opex | 1% of Capex |
| Specific generation (Average) | 3.6 kWh /kWp /day |
| Land required Acre/MWp | 3.2 |
| Land lease cost (Average) | 50,000 Taka/acre/yr |
| Levelized Tariff (as calculated) | 0.11 USD Cents /kWh |

### 7.2.1 Business Model-1

This business model pertains to a solar development company taking land on lease from Grass production farmers

**Table 7-10: – Variable assumptions and result for Business model 1**

| | |
|---|---|
| Solar modules | Mono PERC – Bi facial |
| Structure height | 5m |
| Module tilt | Single Axis Tracking |
| Capex | Plus 30% as compared to Base case |
| Opex | Same as base case |
| Specific generation (Average) | Plus 25% as compared to Base case |
| Land required Acre/MWp | 5.7 |
| Land lease cost (Average) paid by solar company to farmers to cover their loss and some incentive | 35,000 Taka/acre/yr |
| Grass production Revenue | 9.43 Lakh Taka /Acre |
| Grass production Expenses including lease | 4.76 Lakh Taka /Acre |
| Levelized Tariff giving the same IRR as base case (for solar company) | 0.111 USD Cents /kWh |

Analysis – In this business model, the land required per MW of Solar as well as Capex are increasing that increase the Tariff. But the generation is also increasing which is balancing this increase and hence the expected Tariff shall be almost the same as the base case.

### 7.2.2 Business Model-2

This model pertains to an established grass producing company or a big grass producing farmer getting into Solar power generation. The company would setup a subsidiary company for solar project development to whom it would lease the land. The basic structure is the same as in Model-1, the only difference is that the solar development company in this case is leasing land from its own parent company rather than other grass producers as in model 1. The dynamics of this model are similar to model 1 and hence the result is also the same.

### 7.2.3 Business Model-3

This model pertains to a solar development company proposing to develop a new farm with Solar plus Grass production facility.

**Table 7-11: – Variable assumptions for Business model 3**

| | |
|---|---|
| Solar modules | Mono PERC – Bi facial |
| Structure height | 5m |
| Module tilt | Single Axis Tracking |
| Capex | Plus 30% as compared to Base case |
| Opex | Same as base case |
| Specific generation (Average) | Plus 25% as compared to Base case |
| Land required Acre/MWp | 5.7 |
| Land lease cost (Average) for solar | 50,000 Taka/acre/yr |
| Grass production Revenue | 9.43 Lakh Taka /Acre |
| Grass production Expenses including lease | 4.76 Lakh Taka /Acre |
| Levelized Tariff giving the same IRR as the base case | 0.11 USD Cents /kWh |

Since solar and grass production business have almost equal returns, almost similar tariff is required to get an IRR equal to the base case.

This is unlike the case of multipurpose use of Agricultural farms because Grass production has much better returns as compared to vegetable production. Looking at this in practical sense, the Solar development companies may have a very limited interest to get into this business model.

# 8.0 LEGAL AND INSTITUTIONAL ASPECTS

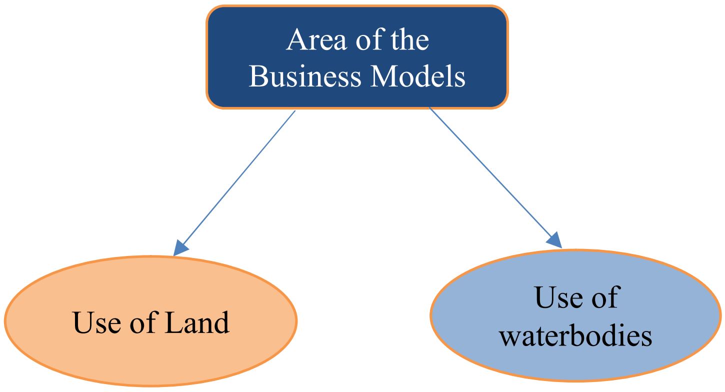
## 8.1 INTRODUCTION

The concept of "Agrivoltaics" was first coined by Armin Zastrow and Adolf Goetzberger in 1981. Although Japan adopted this concept initially, later on, many Countries gradually started to adopt & apply this concept. However, the idea of dual use of land simultaneously under the same sunlight got its name as "Agrivoltaics" in 2011. Countries e.g. Greece, China, and France, have successfully adopted and implemented Agrivolataics in their region. Due to the rapid growth of the Population and industrial pressure, Bangladesh desires to invoke this concept of Agrivolataics on Agricultural Lands for ensuring maximum utilization of the Land. Since this is a new concept for Bangladesh, some legislation may create an obstacle while the implementation of this concept in Bangladesh. Hence, this section of the report is identifies the areas that needed to be fixed before the implementation of this concept. This will help the stake holders to understand the key legal obstacles in developing Agrivoltaics or multipurpose use of the land.

## 8.2 ISSUES RELATING TO THE USAGE

The Business Models presented in earlier chapters have been prepared to ensure sustainable development and develop RE generation facilities along with agricultural farms, animal farms and fish farms. Since Bangladesh has vast land under the above three trades, the Developer will want to use these land areas for multipurpose use and that will fall under the category of dual use of land.

For a better discussion, this report divides the object or area of these business models into the following categories:



### 8.2.1 Use of Lands

In the case of multipurpose use of land, land needs to be used simultaneously for different purposes. In Bangladesh, there are two kinds of land, i.e. Agricultural Land & Non-Agricultural Land. As per the current policies and frameworks of Bangladesh, land can only be used for one purpose either Agriculture or Non-Agriculture. Moreover, the District Agriculture office reports that the agricultural land is declining by 45 hectares every year. In other words, 45 hectares of agricultural land is going to the non-agricultural sector every year. Hence, the Policies and Frameworks of the Country are getting more restricted day by day to protect Agricultural Land.

#### 8.2.1.1 Relevant Laws

- National Land Use Policy,2001
- Land Administration Manuals Volume No.1,2 &3
- Land Management Manual, 1990
- National Agriculture Policy, 2021

#### 8.2.1.2 Areas to be covered

**a) Restrictions of using Agricultural Land for Non-Agricultural Purposes:**

The abovementioned Policies or frameworks strictly constrain the use of Agricultural lands for Non-Agricultural purposes. As per Clause 17.1 of the National Land Use Policy, 2021, Agricultural land should be used for Agricultural Purpose as far as possible. Moreover, the nature of the Agricultural land cannot be converted or changed without the permission of the Concerned Authority. In addition, Clause 5.21 of the Krishi Shomprosharon Niti, 2020, stipulates that the Agricultural land will be protected from Non-Agricultural use of the land. As per Clause 161 of the Land Management Manual 1990, Agricultural land cannot be transferred for conducting any Non-Agricultural Purpose. Apart from this, Rule 7.0 of the Khas Land Settlement Policy, 1997, prohibits the transfer of Agricultural Khas land to anyone except by virtue of Succession. Moreover, the Khas lands are allotted to the Landless people for Agricultural work.

It is also to be mentioned that, the proposed “Krishi Jomi (Jothajotho Bebohar o Shonrokkhon) Ain, 2022”, this law will strictly restrain the use of Agricultural Land for Non Agricultural purposes. Even, Penalty will be imposed for such Non-Agricultural use of the land.

From the above discussions, it is presumed that the Non-Agricultural use of Agricultural land is the main obstacle to the multipurpose use of land.

### 8.2.2 Use of Water Bodies

Since Agricultural land is decreasing, a Floating Solar system can balance the scarcity of Agricultural land for developing this project. Modern technology and scientific innovation have created an evolved idea to develop this model on waterbodies. The general layout of a Floating Solar system is similar to that of a ground-mounted Solar system. Unlike the other Solar Systems, a Floating Solar System is mounted on a floating platform, i.e. waterbodies. Countries like China, Italy, India, South Korea, Germany, etc have already developed Floating Solar Projects. Even Bangladesh has already built up a 10 kW Floating Solar Project in Mongla.

Since these Business models have been framed not only to develop solar panels but also to continue farming and agricultural works, the legal obstacles to developing floating solar systems along with farming of the land, will be discussed in this portion.

#### 8.2.2.1 Applicable Laws

- The Jal Mahal Management Policy, 2009
- Protection of the Natural Waterbodies Act, 2000

#### 8.2.2.2 Areas to be Covered

Jal Mahal Areas: There are a number of Khas Water bodies or water reservoirs in Bangladesh. The Jal Mahal Management Policy, 2009 has been formulated to ensure maximum utilization of such waterbodies by fishing. Except for the small private ponds and the relatively unimportant category of the Wakf estates and Debottar properties owned by religious institutions, all of these are officially Khas and fall under the control of the State. Therefore, the Jalmahal areas will also be considered as a key spot for developing the above-mentioned business models for multipurpose usage. As per Rule 5(4) (e) of the Jalmahal Management Policy, these Jalmahal areas should only be allotted to the “Real Fisherman.” On the other hand, clause 5(4) (n) of this policy, restricts the leasee from granting a sub-lease of the Jalamahal to anyone as well as using the Jalmahal for any other purposes. From the abovementioned analysis, it can be assumed that as per the current rules, this Jalamahal cannot be used for any other purpose except fishing.

Natural Waterbodies: The Government of Bangladesh has enacted the Protection of Natural Waterbodies Act, 2000 to protect not only the natural waterbodies which are identified in the Master Plan of the RAJUK but also the Playgrounds, and open yards. As per section 5 of the above-mentioned act, playgrounds, and natural waterbodies are neither changed nor used for any other purpose without the proper permission of the Government.

## 8.3 TAX ISSUES

As per Section 2(1) of the Income Tax Ordinance, 1984, “Agricultural Income” includes the income generated from granting a right to any person to use the Agricultural land for any period.

Moreover, it has also been laid down in Paragraph 29 of Schedule 6(A) of the Income Tax Ordinance, 1984 that a person whose only source of income is agriculture that stands up to BDT 2,00,000 (two lakhs only) [a year] will be considered as "Agricultural Income," hence avail a tax exemption on such Agricultural incomes. As per the present rule, the Calculation of this scale of exemption is regulated as per the following structure:

| | |
|---|---|
| Total Agricultural Income | XXXX |
| (-) Production Cost 60% | XXX |
| Net Agricultural Income | XXX |

*[Structure No: 01]*

In this particular scenario, the bracket of BDT.2,00,000 applies to the Net Agricultural Income. If the income is started generating from any other sector except Agricultural, the 60% exemption on the Production cost will not be enjoyed by the Marginal Farmers. Hence, the marginal farmers who used to enjoy an additional tax exemption on the production cost will no longer enjoy the said exemption.

Since the Marginal Farmers will lose the Tax exemption on the Production Cost, the Production cost will not be deducted while calculating the Net Agricultural Income as per Structure 01. Hence without the production cost exemption, Net Agricultural Income will not practically possible to keep under the bracket of BDT 2,00,000. Therefore, the proposition of this project under this tax model will not practically be viable. In this regard, the bracket of BDT 2,00,000 may need to be extended, so that the Marginal Farmers can be benefitted even without the Production Cost exemption.

In the case of Income Poultry firms & fish hatcheries, the Tax-free limit for the first BDT 10,00,000 from fish or hatchery Poultry Firms, on the next 10,00,000 will be taxed at the rate of 5%, 10% on the next income of 10,00,000 and 15% tax on the rest of the income (paragraph 1.6 of the Income Tax Poripatra 2022-2023). So, when income will be generated both from the Solar System project as well as Agricultural sources or the Poultry firms at the same time, how the tax duty will be imposed is still a gray area.

Income from Power Generation is considered Non-agricultural income which is enjoying one kind of tax exemption whereas Agricultural Income is enjoying a separate kind of exemption. Since both incomes are enjoying different tax benefits, how the tax duties of these two sectors will be compiled is a big question. So, if an attractive incentive is not formulated in this regard, power generation companies will not be encouraged to invest in Multipurpose projects.

The recent amendment of Section 53J of the Income Tax Ordinance, 1984 imposes a 5% tax on the rent over Private Water bodies. Since Tax duty is imposed on the rent of Private water bodies, the owner of such water bodies will not be interested to give their private water bodies on rent to the investors. This action may create incidental pressure on the Government's water bodies for utilizing this multipurpose project.

## 8.4 RECOMMENDATION

On the basis of the above discussions, the obstacles to the multipurpose use of the Land along with the possible recommendations are pointed out below:

### 8.4.1 Use of Lands

**Table 8-1: Use of Land**

| | Legislations | Obstacle | Possible Solution |
|---|---|---|---|
| **Use of the Land for Non-Agricultural Purposes** | **1. National Land Use Policy, 2021**<br>**2. Krishi Shomprosharon Niti, 2020**<br>**3. Land Management Manual 1990** | Agricultural lands can only be used for Agricultural purposes | a) Certain Agricultural lands shall be marked and allowed to use for multipurpose regardless of any law of the Country.<br>b) According to Dr. Charles Worringham the report Author & Contributor of the Institute for Energy Economics and Financial Analysis (IEEFA), "certain crops can tolerate moderate shading and that during extreme heat, some may even benefit from lower temperatures and improved soil moisture." The Government may conduct research and identify the crops. Then may specify those crops to be cultivated in the land where the Solar project is proposed to be established.<br>c) Government should put a capping on possible loss to the crop yield to 10% arising out of multipurpose use |
| **Restriction in transferring Khas Land** | **Khas Land** | Khas Lands only be transferred by way of succession and | When Khas Land only be used for Agricultural Purpose and transferred through succession, this land cannot be used for other purposes. This may limit the proper utilization of the |

| | Legislations | Obstacle | Possible Solution |
|---|---|---|---|
| | **Settlement Policy, 1997** | used the land for Agricultural Purposes only | Khas lands.<br>Since sublease is prohibited by section 75A of the State Acquisition & Tenancy Act, 1950, the khas lands cannot be transferred through a lease. On the other hand, Land transfer through succession does not warrant the proper utilization of the Khas Land. If some portions of the Khas Lands can be allowed to use for multipurpose, it will come out with a maximum benefit. So, the policymakers should think vastly to find out a convenient way that can synchronize farming and establish solar systems at the same time on the khas land. |

### 8.4.2 Use of Water Bodies

**Table 8-2: Use of Water Bodies**

| | Legislation | Obstacle | Possible Solution |
|---|---|---|---|
| **Lease of Jalmahals** | **The Jalmahal Management Policy, 2009** | Jalmahal should be allotted to the "Real Fisherman" and not permitted to sublease or use for any other purpose. | Since Khas lands are not permitted to be sublet under the State Acquisition and Tenancy Act 1950, the Khas Jalmahal cannot be allowed to sublet as well.<br>In this regard, the use of the Jalmahal can be made flexible which is now restricted by the use of fishing only. It is assumed that if certain khas Jalmahal is allowed to use for Multipurpose it may bring a fruitful outcome. |

### 8.4.3 Tax Issues

**Table 8-3: Tax Issues**

| | Obstacle | Possible Solution |
|---|---|---|
| **Tax Duties** | a) The benefit of Production Cost exemption in respect of Agricultural Income cannot be enjoyed from Non-Agricultural Income. If the Agricultural land is used for Non-Agricultural purposes as well, the income generated from such lands will not get a production cost exemption. | a) In this regard, the bracket of tax exemption up to BDT 2,00,000 on Agricultural Income, is needed to be extended. |
| | b) The exemption enjoyed by the Power business sector is completely different from the exemptions enjoyed by the Agricultural Income. | b) Tax duties in respect of the income generated from the Multipurpose use of the Land will be specified. A separate tax head along with special and attractive Tax incentives can be formulated, this may encourage investors to invest in this sector. |
| **Tariff Rate** | Imposition of Tariff Rate | Generally in Solicited Project Proposal, a convenient Tariff rate is proposed by the proposer. Since Multipurpose use of land is newly being introduced in the business sector of Bangladesh, the Government may increase the Tariff rate from the regular rate imposed on other sites. So that the investors get attracted to invest in this project. |

## 8.5 CONCLUSION

The use of agricultural land for non-agricultural purposes is itself a major obstacle to execute this project under the current legislation of Bangladesh. However, this project neither fully converts Agricultural land to Non-agricultural land nor uses Agricultural land fully for Non-Agricultural purposes rather this project promotes the simultaneous use of Agricultural land. Since the Multipurpose use of land is a new concept for Bangladesh, no specific legislation is currently prevailing to regulate this matter, moreover, drawbacks of relevant Legislation are yet to be resolved. Hence, this report has tried to portray the major areas which may create obstacles in the practical execution of the project. Although the possible solutions are recommended, these are not conclusive solutions. The legislators by their discretion may find out the best possible solution to address the above-discussed issues.

# 9.0 EXISTING PLANT VISITS IN BANGLADESH

## 9.1 BACKGROUND

It is required to assess the scope of Agri PV in the existing solar PV plants. In this context two plants have been visited whose information is given below. All the photographs and data presented is courtesy HDFC Sinpower Limited

## 9.2 HDFC SINPOWER LIMITED

The high level details of the plant are given below:

1. Plant name - HDFC SinPower Limited 50MW Ac solar Park at Sutiakhali, Gouripur, Mymensingh
2. Owners name -SPV of Sinenergy Holdings Pte Ltd, Ditrolic Solar Malyasia & IFDC Solar BD
3. Construction start date - September 2019
4. COD -4th November 2020
5. Plant land area - 174 acres
6. Plant Capacity - AC (50MW)
7. Plant Capacity - DC (73 MWp)
8. Solar panel capacity - 430wp & 435 Wp
9. Solar panel numbers -1,69,092
10. Solar panel make - Longi Monocrystalline, Bi-facial
11. Inverter type - String
12. Inverter capacity - 175 KW each
13. Inverter numbers - 336
14. Inverter make - HUAWEI
15. Inverter voltage AC - 0.8KV
16. Inverter voltage DC - 1500
17. PPA value - Tk / kwh - $ 0.17
18. PPA duration (Number of years)- 20
19. Module mounting Structure height - 14.5 mpwd
20. Module mounting Structure Material - Hot dipped Galvanized
21. Module mounting Structure Type - Fixed
22. Mounting angles of Panels -15-19 degree
23. Minimum Ground clearance of panels - 2 mtr
24. Panel mounting type - Double Portrait
25. Pitch - Centre to centre distance of panel rows - 6 m
26. Evacuation level to grid - 132kV
27. Distance to connecting Substation - 5.4km
28. Type of conductors for evacuation to substation - ACSR Grossbeak & Copper for underground
29. Any agricultural activity - Not yet
30. Main transformer Capacity and numbers - 60 MVA
31. Inverter transformer capacity and numbers - 5 MVA, 12nos


**Figure9-1: HDFC Sin Power 50 MW plant, Mymensingh**

The plant is on riverside and therefore the area is flood prone.

**Figure9-2: Plant on riverside**

The minimum ground clearance of the panels is kept to be 2m, however the height varies and can go more than 5m as seen in picture below:

**Figure9-3: High structure to take care of flood level.**

Other elements are also raised suitably to take care of the possible floods

**Figure9-4: Transformer on raised platform.**

At present there is no agricultural activity taking place in the plant but the management has shown keen interest in the same and are willing to try.

## 9.3 SPECTRA SOLAR PARK LIMITED

This plant has a 35 MW AC capacity and is on the Bank of Padma River in Manikganj. Spectra Solar Park Limited (SSPL) is a joint venture between Spectra Engineers Limited and Shunfeng Investments Limited, a Hong Kong based company. The plant achieved Commercial Operation Date (COD) at the beginning of 2021. All the photographs and data presented is Courtesy Spectra solar park limited.


**Figure9-5: Spectra solar plant**

The high level details of the plant are given below:

1. Plant name – Spectra Solar Park
2. Owners name – Khan Md. Aftabuddin, Managing Director
3. Construction start date – January 2020
4. COD –12, March 2021
5. Plant land area – 139 acre
6. Land type (owned / leased) – owned
7. Land cost or Lease amount per acre / per year – Not provided
8. Plant Capacity – AC (35 MW)
9. Plant Capacity – DC (45.38 MWp)
10. Solar Panel Type – Poly crystalline
11. Solar panel capacity – 330 wp
12. Solar panel numbers –137,520
13. Solar panel make - Suntech
14. Inverter type – Central
15. Inverter capacity – 3.125 MW
16. Inverter numbers – 12
17. Inverter make – Sungrow
18. Inverter voltage AC – 600
19. Inverter voltage DC – 1500
20. PPA value – $ 0.139/kWh
21. PPA duration (Number of years)- 20

22. PR committed by EPC / Developer - 77.71%
23. PR obtained so far – 78% +
24. CUF obtained so far – 20%
25. Module mounting Structure height – 10.76 (HFL)
26. Module mounting Structure Material – Hot dipped GI
27. Module mounting Structure Type – Fixed
28. Mounting angles of Panels –14 degree
29. Minimum Ground clearance of panels – 1.5 m
30. Panel mounting type – Double Portrait
31. Pitch - Centre to centre distance of panel rows – 6 m
32. Evacuation level to grid – 33kV
33. Distance to connecting Substation – 8.4 km
34. Type of conductors for evacuation to substation – Al
35. Any agricultural activity – yes (Chilli, peanuts, turmeric etc)
36. Experience with crops– Ok
37. Inverter transformer capacity and numbers - 6.25 MVA, 6 nos

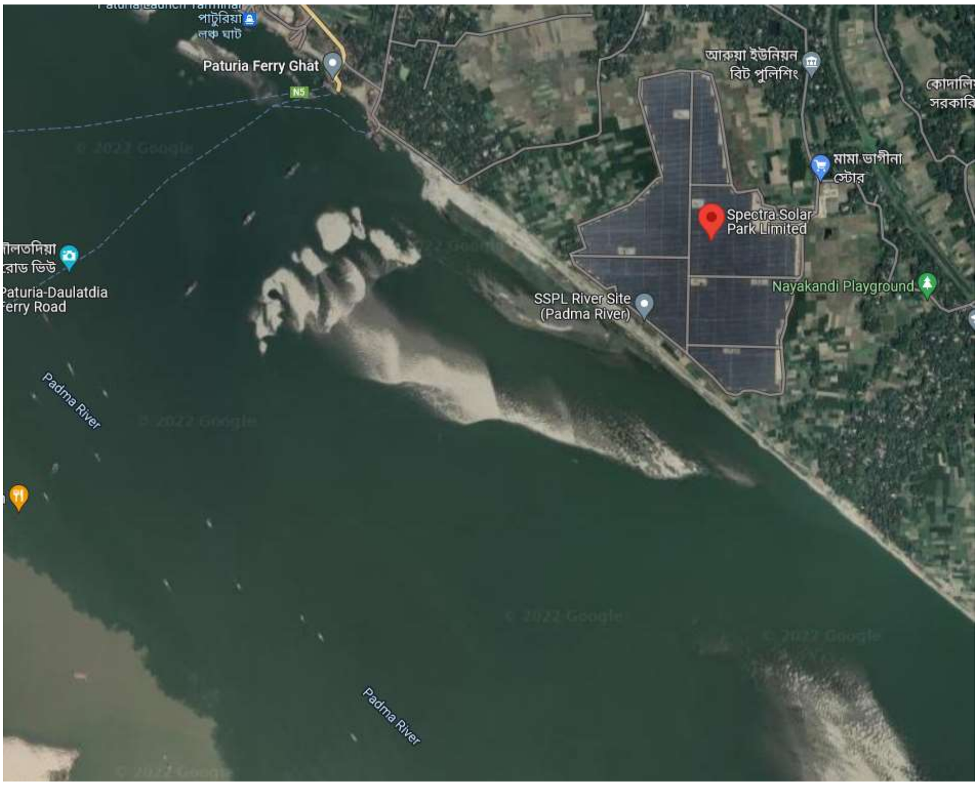



**Figure9-6: Google location of plant**

So just like other riverside plants, care has to be taken to avoid damage in case of floods

Figure9-7: River Padma on South West side of the Spectra solar plant.

The panels have high ground clearance as shown in picture below:


Figure9-8: High ground clearance to beat the floods

Taking advantage of the high ground clearance, the plant has tried turmeric and peanut plantation below the panels and have obtained good results specially with peanuts.

**Figure9-9: Turmeric plantation below the panels.**

## 9.4 SOLAR IRRIGATION PUMPS (SIP)

The World Bank is supporting the Bangladesh government's effort to install solar-powered irrigation pumps. The low-cost technology is well suited for the country's flat terrain and abundant sunshine.The Rural Electrification and Renewable Energy Development Project II (RERED II) is piloting solar-powered irrigation solutions using a public-private partnership model. The implementing agency, Infrastructure Development Company Limited (IDCOL) channels grant and credit funding to the nongovernment organizations and private investors who install the solar pumps. The details of the program are as under:

| | | |
|---|---|---|
| **Pump Capacity** | - | 11 $kW_p$to 40 $kW_p$(0.75–2 million liters of water/day) |
| **Coverage** | - | 4–16 hectares/pump for Paddy |
| **Approved** | - | **1,630**pumps (45 $MW_p$approx.) |
| **Installed** | - | **1,514** pumps (40 $MW_p$) |
| **Coverage** | - | **15,958** hectare |
| **Emission Reduction** | - | **10,519**ton CO2e/yr. |
| **Target** | - | **10,000**by 2025 |
| **Finance** | - | Equity-15%, Loan-35%, Grant-50% |
| **Funding source** | - | |
| • **Grant – 50%** | - | BCCRF, GPOBA, KfW, USAID, ADB |
| • **Loan – 35%** | - | IDA, JICA |

### 9.4.1 Year wise installation of SIPs

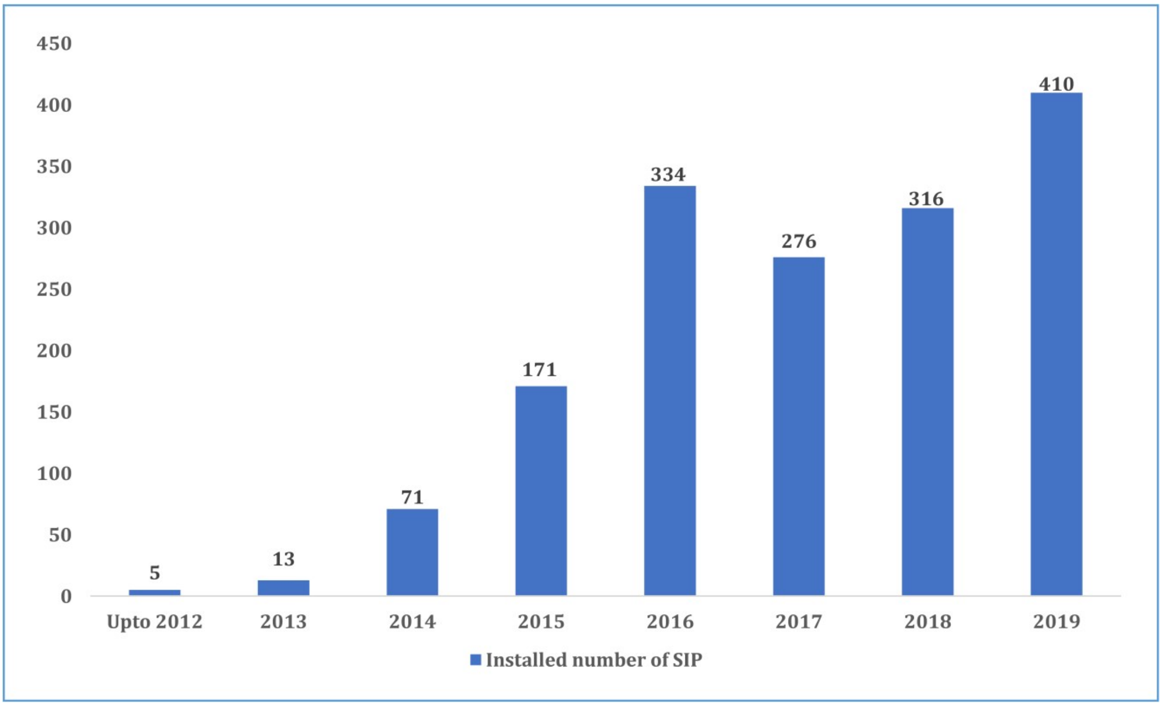



**Figure 9-10: Yearwise Installation of solar irrigation pumps**

### 9.4.2 Benefits of solar pumps over diesel pumps

| | Problems with Diesel Pumps | Benefits of Solar Pumps |
|---|---|---|
| Tariff | Extraction cost per liter is higher | 20-30% lower |
| Service | Frequent technical problems | Suppliers provide necessary service |
| Maintenance | High maintenance cost | Maintenance cost is very low : Long life |
| Operation | Higher OPEX | Lower OPEX |
| Environment | Detrimental | Zero carbon emission |

**Figure 9-11: Diesel pump Vs Solar pump**

### 9.4.3 Site Selection Criteria

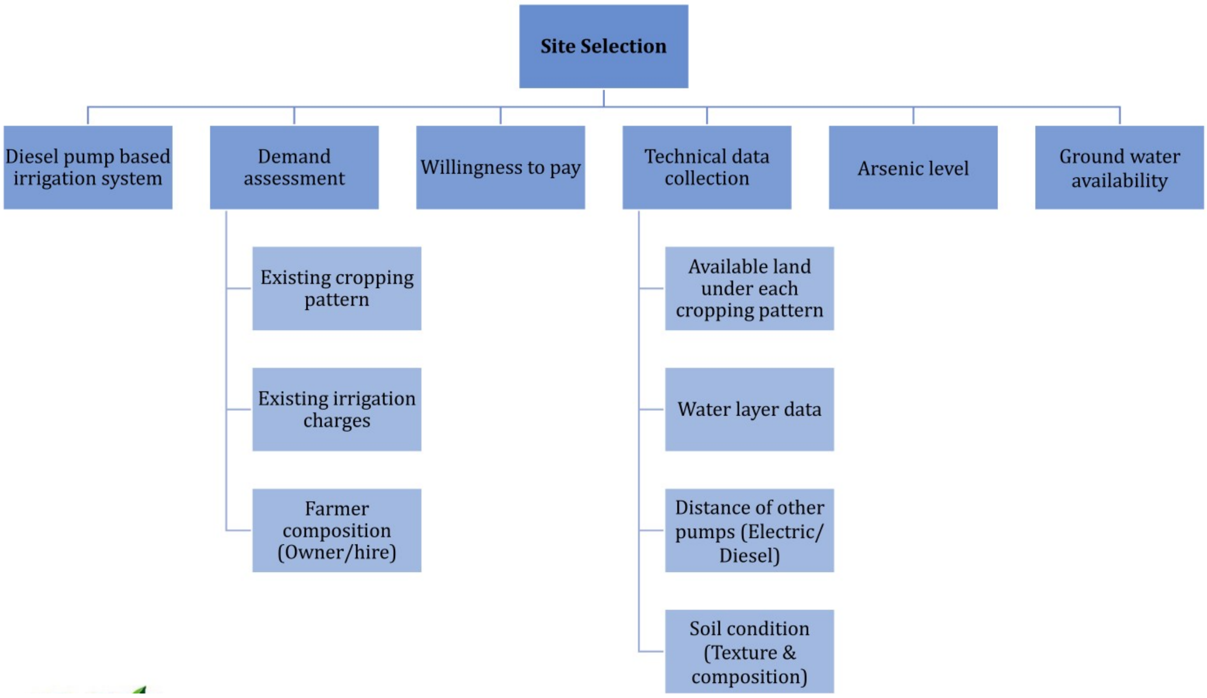



**Figure 9-12: Site Selection Criteria**

- Fulfilling criteria set by Upazila Irrigation Committee
- Off-grid areas with no electric pumps
- Availability of fossil fuel based existing irrigation system
- Two or three crop based cropping pattern
- Arsenic levels within allowable range
- Sound water level and ground water replenishment rate
- Majority of farmers willing to avail the service

**Possible link between the Multipurpose Land use and SIPs**

- The Design and layouts created for the Multipurpose land use may be adopted for Solar panels of SIP so that the land required for SIPs can have the multipurpose usage.
- For the above, the solar panels for SIPs belonging to fields that are close by, can be combined in a single field for cost optimization.

# 10.0 STUDY OF SIMILAR PROJECTS – AN INTERNATIONAL PERSPECTIVE

# STUDY OF SIMILAR PROJECTS – AN INTERNATIONAL PERSPECTIVE

## 10.1 GENERAL

In order to capture the experience of plants coming up around the world in the similar climate conditions, a few plants in India have been visited and studied. The lessons learnt from the challenges faced by these projects in India can provide deep insight during conceptualizing, planning and construction of similar type of projects in Bangladesh.

In view of the above, the following Agrivoltaic Solar Power Plants were visited in India

1. 100 kW plant at National Institute of Solar Energy (NISE), Gurugram, Haryana India
2. 110 kW plant at Krishi Vigyan Kendra (NHRDF) Ujwa, Delhi, India
3. 10 kW plant at Amity University, Noida, Uttar Pradesh, India
4. 12 MW plant at Cochin International Airport Limited (CIAL), Kerala, India

In addition to the visits, information is taken from the literature survey. In this context, we acknowledge the information taken from the study report "Agrivoltaics in India, Overview of operational Projects and relevant Policies" as commissioned by Indo German Energy Forum in May 2021 and produced by NSEFI (National Solar Energy Federation of India).

## 10.2 SALIENT FEATURES

The salient features of the above projects are shown in table below:

### 10.2.1 Agrivoltaic plant at National Institute of Solar Energy (NISE) Plant, Gurugram – 100 kW

**Table 10-1: Salient Features of NISE Plant**

| Attributes | Description |
|---|---|
| Installed capacity DC, kWp | 100 |
| Place | Haryana, near Gurgaon |
| GPS location | 28.42754, 77.16071 |
| Project commercialization level | Research |
| Project developer | National Institute of Solar Energy (NISE) |
| EPC | Tata Solar |
| Type of crop plantation | Interspace |
| Tracking | No |
| Type of soil | Mostly Loamy sand |
| Crops that have been tried | Tomato, chili, flowers, Kufri Lima potato |

NISE has tried the plantation of tomato, chilli and flowers between and below solar arrays in one part of an plant.

Some photographs of NISE plant are as under:

**Figure10-1: Experimental agriculture at NISE**

NISE is studying the impact of level of Albedo and its impact on generation of bi-facial panels by trying different types of surfaces below the panels. This will generate important data for possible use of bi-facial panels in Agrivoltaics.

**Figure10-2: Bi-facial solar panels at NISE**

NISE is also doing study similar study on vertical Bifacial panels.

Figure10-3: Vertical solar panels at NISE

Figure10-4: Another view of vertical solar panels at NISE

### 10.2.2 Agrivoltaic plant at Krishi Vigyan Kendra (NHRDF) Delhi - 110 kW

**Table 10-2: Salient Features of KVK Plant**

| | Description |
|---|---|
| Project name | Krishi Vigyan Kendra (KVK) Ujwa Solar Farm |
| Date of commission | February, 2021 |
| Installed capacity DC, kWp | 110 |
| Land used | 2000 m2 |
| Place | Ujwa, Delhi |
| GPS location | 28.57134, 76.89579 |
| Type of project | Research |
| Project developer | Krishi Vigyan Kendra (KVK) under National Horticultural Research and Development Foundation (NHRDF), Ujwa, NewDelhi |
| EPC | Oakridge Energy Pvt. Ltd. Noida |
| Ownership structure | Land and farming by Krishi Vigyan Kendra, Ujwa, New Delhi Agrivoltaic plant owned by Oakridge Rooftops Pvt Ltd. |
| Operation & Maintenance | Oakridge Rooftops Pvt Ltd. |
| Type of plant | Elevated structure |
| Module technology | 335 Wp poly crystalline |
| Mounting structure | Hot dipped galvanized steel structure with 3.5 m elevation height at 15 degree tilt |
| Tracking | Fixed tilt |
| Sale of power | To Discomwith a tariff of INR 3.13 / kWh. |
| Agricultural aspects | Temperature range 2-47 degree centigrade.<br>Soil with PH of 8.5 and above. |
| Crops | Okra, tomato, brinjal, capsicum, leafy vegetables, rootvegetables and cole crops planned |
| Crop cultivation | Start in May 2021 |

It is proposed to study the impact of shade on the yield at this installation. For this purpose, exactly same beds have been prepared in the PV area as well as open area.


**Figure10-5: Same Beds in PV and Open Areas**

Some passage is required for walking of maintenance or panel cleaning staff as shown below:

**Figure10-6: Pathway for maintenance or cleaning staff**

The loss of yield can be compensated by taking advantage of the height of the structure to create a trellis and growing suitable vegetablese.g. ridge gourd.

**Figure10-7: Trellising of vegetables with wires tied to solar structure**

**Figure10-8: Crop bed is under preparation at KVK**

### 10.2.3 Agrivoltaic plant at Amity University, Noida - 10 kW

**Table 10-3: Salient Features of Amity University Plant**

| | Description |
|---|---|
| Date of commission | 2017 |
| Installed capacity DC, kWp | 10 |
| Place | Uttar Pradesh, Gautam Buddh Nagar District, Noida |
| GPS location | 28.54162, 77.33241 |
| Financing structure | Project cost 24.9 lakh INR<br>Electricity used for self consumption |
| Type of agrivoltaic plant | Single column |
| Module technology | • Monofacial, polycrystalline (330 Wp), Canadian |
| Mounting structure | • Approximately 15 ft (4.6 m) height of the mounting pole<br>• Area: 630 m2; 159 kWp/ha |
| Tracking | None |
| Cleaning | • Automatic piping system for sprinkler module cleaning |
| Soil type | • Sandy loam soil |
| Crops tried | Maize, potato, brinjal, mustard |

Some photographs of Amity University plant are as under:

**Figure10-9: Farming under solar panels at Amity**

**Figure10-10: Another view of solar panels at Amity**

### 10.2.4 Agrivoltaic plant at Cochin International Airport Limited, Kerala–12 MW

**Table 10-4: Salient Features of CIAL Plant**

| Attributes | Description |
|---|---|
| Project name | Cochin International Airport Limited (CIAL) |
| Date of commission | 18.08.2015 |
| Installed capacity DC, kWp | 12,000 (partly co-located with agriculture)<br>Total capacity in 2020 above 26,000 |
| Place | Kerala, Cochin |
| GPS location | 10.15667, 76.38253 |
| Type of project | Commercial |
| Project developer | Bosch Ltd. |
| EPC | Bosch Ltd. |
| Plantation | Interspace |
| Module technology | 265 Wp Renesola, inverters 1 MW by ABB India |
| Mounting structure | Conventional ground mounted PV design, Fixed tilt |
| Cleaning | Manual cleaning with water |

| Attributes | Description |
|---|---|
| Crops | • Tomato<br>• Ginger, turmeric, green chilli<br>• Snake gourd, bitter gourd, bottle gourd, ash gourd, blonde cucumber, eggplant<br>• Pumpkin<br>• Ladies finger<br>• Long beans |
| Crop cultivation | 60-80 tons per year cumulative production reported. Completely organic cultivation. There is strong market linkage and direct selling to regular consumers and passengers which helps the unit to earn revenue from agriculture part. Most of it is interspace cultivation. |
| Further aspects | PV capacity has been extended to above 26 MW until 2020. |

This project was initially conceptualized as a normal Ground mounted PV with structure height and design as done for any typical ground mounted PV plant.

Later on with a view to ensure optimum land utilization CIAL decided to go for organic farming in the plant. This provides an excellent learning for the solar plants which are already constructed as a normal Ground mounted plant and intend to do farming also in that.

Some photographs of CIAL plant are as under:


**Figure10-11: Crop sown at CIAL**

**Figure10-12: Cowpea sown at CIAL**

**Figure10-13: Pumpkin grown at CIAL**

Figure10-14: Cauliflower grown at CIAL

Figure10-15: Floating Solar at CIAL

# 11.0 ENVIRONMENTAL ASPECTS

## 11.1 AFFECT OF AGRI PHOTOVOLTAICS ON ENVIRONMENT

The most important issues for agricultural practice underneath an Agrivoltaic plant is the alteration of microclimate conditions and the resulting consequences for crop cultivation. While the reduction in solar radiation underneath the panels is expected to be the most apparent change, several other microclimate factors may also be affected.

Studies have been done to assess the impact of Agrivoltaics on the environment. The findings of some of the studies are as under:

- Significant changes in daily mean temperatures and thermal time between an Agrivoltaic area and an unshaded area at the French location of Montpellier were observed. On a few days with low wind speed or high solar radiation, the air temperatures underneath the panel tended to be higher.

- It was found that soil temperature decreased in shaded areas as compared to full-sun conditions. This inconsistency may be due to the direct effects of the solar panels on air temperature observed in studies with ground-mounted solar parks and the heterogeneous shading conditions underneath Agrovoltaic facilities.

- Temperature and radiation — described by the photothermal quotient — are in general two of the most important determinants of cereal grain yields. In addition, temperature can affect nutritional quality, for example fatty acid composition of oilseed rape and starch content of potatoes. While air temperatures tended to be higher, soil temperatures decreased underneath the panels. Also, whereas the crop temperatures of durum wheat, lettuce and cucumber cultivated under the panels decreased during the day-time, the same increased during the night-time.

- Use of solar panels leads to an altered water distribution underneath. After heavy rainfall, direct water runoffs onto the soil surface can increase the risk of soil erosion, while in more sheltered parts, unevenly distributed rainfall can lead to diminished water availability.

- The sheltering by the PV panels could help reduce the infestation of fungal diseases after persistent rainfall.

- In studies with Agrovoltaics systems adapted for crop production, for example through a reduced module density, crop-available radiation was predicted to reach values ranging between 60 and 85% of that in open-field conditions. This effect will be less distinct in smaller Agrovoltaics facilities due to border effects, especially when the sun is low and structures are higher and can reach the ground from the sides.

There is very little information on the effects of APV on crop production in the form of a long term compiled data and is particularly lesser for climatic conditions similar to Bangladesh.

The considered design for Agrivoltaics and grass production area in this report has 5m panel height at a pitch of 7.52m and Single Axis Tracking. This design ensures that almost 90% of land area has shading of less than 40% which negates the fears of non uniform temperature of air and soil in the shaded areas. The tracker helps homogeneity of radiation and temperature below the panels and also water distribution in case of rains.

## 11.2 AFFECT OF FLOATING SOLAR PANELS ON WATER BODIES

According to a recent study by researchers in the U.K. and U.S.A, floating solar might interfere with interaction between the water body and the atmosphere, causing the occurrence of deep-water anoxia (absence of oxygen), resulting in the release of phosphorus from bed sediments.

Phosphorus is found in sediment bed naturally and is released in the water at a much slower rate. During deep water anoxia, which can get induced due to reduction in surface heating and wind mixing, the sediment starts releasing phosphorus.

As a result of the reduced sunlight, floating solar plants can also cause large areas of uneven surface heating, lowering reservoir turnover efficiencies, and impacting plant growth in the littoral zone (near shore area where sunlight penetrates all the way to the bottom of the water body, allowing aquatic plants to grow). Experts say that the effect of solar panels on a water body is highly uncertain and will differ depending on the water body form and floating solar architecture. As in the case of Agrivoltaics, here also a published data of impact especially in similar conditions as of Bangladesh is very little.

The considered design for floating solar in fish ponds has only 40% coverage of the water surface. Such a low coverage will negate the fear of above mentioned points.

# 12.0 CONCLUSION

## 12.1 THE POTENTIAL FOR MULTUPURPOSE USE WITH RE

The total potential of multipurpose use of land with RE for three basic trades i.e. Agriculture farms, animal farms and fisheries put together is 22,616 MW. The individual potential of three trades is given below.

### 12.1.1 Potential of Agrivoltaics (Multipurpose use with Agricultural farms)

The total area of agricultural land under 40% shade tolerant crops in various divisions is as follows:

**Table 12-1: Area under 40% shade tolerant crops in various divisions**

| Division | Area under 40% Shade tolerant crops (Acres) |
|---|---|
| Barisal | 55,440 |
| Chittagong | 1,54,585 |
| Dhaka | 1,59,127 |
| Khulna | 99,616 |
| Mymensingh | 81,356 |
| Rajshahi | 3,43,712 |
| Rangpur | 3,23,940 |
| Sylhet | 50,648 |
| Total | 12,68,424 |

Data source – DAE, 2021 and further calculations

An analysis of irradiance map of Bangladesh, shows that atleast 50% of nation has yearly GHI of over 1700 kWh /sqm which is suitable for solar PV installation. So considering 50% of the above area as suitable for multipurpose use, the suitable area is around 6,34,212 acres.

For agricultural field the area required per MW of solar as calculated in earlier sections – 4.2 acres

So, theoretical potential is 6,34,212 /4.2 = 1,51,003 MW

However, in addition to satisfying the conditions of good radiation and shade tolerance of crops, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e.around 21 acres must be available either in a single farm (not very likely) or as a combination of small fields located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 10% of 1,51,000 MW theoretical potential will meet this criteria and hence the practicable potential would be around 15,100 MW.

### 12.1.2 Potential of Agrivoltaics (Multipurpose use with fish farms)

As discussed in the earlier sections, the large water bodies do have floating solar potential but will not be considered as multipurpose use as the water bodies are very large and its always possible to find areas for fishing and solar separately. Therefore, areas under intensive and highly intensive fish farming (small farms) alone have been considered for potential calculation of multipurpose use of RE with fisheries.

**Table 12-2: Pond area for fish varieties in Bangladesh under intensive and highly intensive categories**

| Division | Intensive | Highly intensive | Total (Ha) |
|---|---|---|---|
| Dhaka | 15,578 | 1,688 | 17,266 |
| Mymensingh | 16,623 | 10,726 | 27,349 |
| Khulna | 13,835 | 2,583 | 16,418 |
| Barishal | 6,319 | 40 | 6,359 |
| Rangpur | 11,313 | 640 | 11,953 |
| Rajshahi | 23,674 | 1,336 | 25,010 |
| Chattogram | 18,264 | 1,266 | 19,530 |
| Sylhet | 4,223 | 133 | 4,356 |
| Total | 1,09,829 | 18,412 | 1,28,241 |

Reference: Department of Fisheries (DoF), 2021. Yearbook of fisheries statistics of Bangladesh, 2019-2020. Department of Fisheries, Bangladesh

Total area in this category – 128,241 Ha or 3,16,884 acres

As explained earlier, an analysis of irradiance map of Bangladesh, shows that atleast 50% of nation has yearly GHI of over 1700 kWh /sqm which is suitable for solar PV installation. So considering 50% of the above area as suitable for multipurpose use, the suitable area is around 1,58,442 acres.

For fish ponds the area required per MW of solar as calculated in earlier sections – 6.6 Acres

So, theoretical potential is 1,58,442 / 6.6 = 24,006 MW

However, in addition to satisfying the conditions of good radiation, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e. around 33 acres must be available either in a single farm (not possible) or as a combination of small farms located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 5% of 24,006 MW theoretical potential will meet this criteria and hence the practicable potential would be around 1200 MW.

### 12.1.3 Potential of Multipurpose use of RE with animal farms

The total area of land producing grass with 30% shade tolerance is around 9 Lakh acres, as explained in the earlier chapters.

As explained earlier in this chapter, an analysis of irradiance map of Bangladesh, shows that at least 50% of nation has yearly GHI of over 1700 kWh /sqm which is suitable for solar PV installation. So considering 50% of the above area as suitable for multipurpose use, the suitable area is around 4.5 lakh acres.

For grass field the area required per MW of solar as calculated in earlier sections – 5.7 acres

So, theoretical potential is 4,50,000 / 5.7 = 78,947 MW

However, in addition to satisfying the conditions of good radiation and shade tolerance of grass, many other practical conditions are also to be met e.g. a contiguous area for atleast 5 MW i.e. around 28.5 acres must be available either in a single farm (not very likely) or as a combination of small fields located close-by. There is no data available to establish as to how much this area is likely to be.

For calculation purpose it is assumed that about 8% of 78,947 MW theoretical potential will meet this criteria and hence the practicable potential would be around 6316 MW.