Potential for Solar Irrigation Pumps (SIPs) in Bangladesh

POLICY BRIEF

Report prepared for Sustainable and Renewable Energy Development Authority of Bangladesh (SREDA)

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1 Introduction

This policy brief summarises the key findings and policy recommendations resulting from the development of the *'Solar Irrigation Pump (SIP) Site Prioritisation Tool'*. The tool has been developed for the Sustainable & Renewable Energy Development Authority), SREDA henceforth, (and other stakeholders) by an international consulting team of Vivid Economics and PwC, with support from local consultancy NACOM. It follows previous work with SREDA to scope the market potential and develop potential business models for solar mini-grids, solar irrigation, and solar boats.

Solar irrigation has vast potential in Bangladesh to contribute to socioeconomic development and the attainment of the commitments to reduce greenhouse gas emissions. In its Nationally Determined Contributions (NDC) and associated action agenda, the government commits to reduce emissions by 5% compared to the business as usual baseline by 2030 – and by a further 15% conditional on mobilising support from international sources of finance. Similarly, the government is committed to reaching 10% of installed electricity generating capacity by renewable energy, up from just 3% today. As a part of these ambitions, SREDA and other stakeholders[1] have discussed the ambition of developing 25,000 solar irrigation pumps in the next five to ten years, up from about 1,500 deployed to date[2].

The objective of this policy brief is to (i) provide an overview of the analytical '*SIP Site Prioritisation Tool*', (ii) present key results from the '*SIP Site Prioritisation Tool*', and (iii) describe policy issues and options. The tool provides insights for key policy areas that may need to be considered in order to unlock the full technical and economic potential of the SIP market and proposes a range of potential policy responses to each issue.

The policy areas discussed in this note are:

- Prioritising the roll out of SIPs in the most advantageous regions
- Selling surplus power from SIPs to the main grid
- Accounting for uncertainty in the revenue generating potential of SIPs

The remainder of this brief is structured as follows:

- Section 2 provides an overview of the technical scope of the tool and is supported by a technical annex. It also lays out the key assumptions, caveats and limits to the tool.
- Section 3 presents the key findings of the tool in terms of feasibility and attractiveness of rolling out SIPs nationwide. It describes the most advantageous areas identified and how the SREDA policy ambition of reaching 25,000 SIPs in the next five years could be achieved.
- Section 4 discusses the potential for connecting SIPs to the main grid to sell surplus power. It identifies the total power that could be sold to local distribution networks and describes some of the key policy issues around developing a net metering policy, including seasonality of power availability.
- Section 5 discusses revenue uncertainty from SIPs relating to crop patterns and usage for irrigation and proposes ways to mitigate this revenue risk.

[1] Figures raised during a workshop held at SREDA, Bangladesh, in preparation of this study, in July 2019.
[2] Based on data supplied by IDCOL in preparation for this study.

2 Tool Overview

2.1 Intended audience

The tool has been developed in the first instance for the government of Bangladesh with SREDA as the owner and main user. However, the data gathered, and functionality provided by the model may also be of interest to a broad range of other stakeholders including potential funders of SIPs (concessional or commercial) and others where business models are predicated on enhanced irrigation coverage in the country. For the government, the tool shows the priority areas across the country, and the total potential of solar irrigation. It also reveals the need for the consideration of policy options, such as the possibility of selling surplus electricity generation back to the grid, to enhance the economic feasibility of pumps.

For financers and developers, the tool can both be a first pass at indicating areas for development, and a method of verification that they are not being misled with information. The tool is not a replacement for local surveying and assessing of the economic and technical conditions but does provide pre-feasibility, macro level guidance that may enable the efficient allocation of investment required to carry out such tasks in areas with greater pump potential.

2.2 Tool Details

The '*SIP Site Prioritisation Tool*' seeks to identify priority sites in Bangladesh for investment in SIPs, through a structured economic model of both the potential demand for SIPs, and the cost environment to supply these services. It does this through a combination of (i) collating and standardising a wide range of geospatial data, from a large number of international and national data sources, and (ii) economic modelling of the revenue generating potential and economic costs of deploying SIPs for every 2km^2 'grid cell' across Bangladesh (each 2km^2 or 400 hectares square of land considered is frequently referred to as a grid cell).

The tool creates an attractiveness measure for solar irrigation, ranked from 0 to 10, with 10 being the most feasible locations. The measure of attractiveness is constructed from both supply and demand side elements. The tool calculates the number of SIPs that could be technically feasible in each 2km^2 grid cell and ranks the cells against each other.

On the demand side, the tool considers a lease model for farmers, where the SIPs remain under private sector ownership and farmers are charged a fixed price for irrigation, for a given crop/season. The tool assumes prices are set according to IDCOL estimations of the optimal local price for irrigation, based on local surveying. The costs include the full costs of providing pumps, and do not consider the possibilities of any subsidies or grants. Additional support would increase the financial viability of pumps by increasing the potential returns to the private investors but would not change the overall economic feasibility of the pumps.

On the supply side, the pump configuration needed to meet the expected baseline demand is calculated. The costs of this pump configuration depend on the groundwater depth, the presence of a surface water source and local solar conditions. The easier water is to access, the lower the costs, with the presence of surface water leading to the choice to construct surface water pumps. The greater the solar availability, the lower the costs. The cost factors are listed in Table 1.

Table 1 Supply Factors

Variable	Description	Unit
Solar availability – January [etc.]	Effectively similar to hours of direct sunshine per day, per month of the year	kWh/m2/day
Groundwater depth	Depth of Groundwater below surface	metre
Location of surface water	Vector of surface water location	

Source: Vivid Economics

For a baseline demand scenario, the tool considers how the need for pumped irrigation varies across the country. This is estimated on the basis of current cropping patterns, and the evapotranspiration in each region, which gives an estimate of the water requirements to cultivate the crops currently grown. Local rainfall patterns are then accounted for, leaving a net irrigation requirement for each crop type, in each month, in each region. The assumption is made that the total land under cultivation remains fixed under all scenarios and the model does not account for marginal lands becoming cultivated as irrigation access improves.

Table 2 below shows the key demand factors. In addition to these factors, which determine the potential revenue from providing irrigation services, two further cases are considered for each grid cell:

- How much demand there would be if all excess electricity is sold to the grid – discussed in section 4.
- How much demand there could be if excess electricity generated could be sold to the local population, which is proxied by the population density.

Table 2 Demand Factors

Variable	Description	Unit
Power demand from irrigation	Electrical demand for power for irrigation	kWh
Water demand for irrigation	Pump requirement for irrigation	litres cubed
Crop grown – *BORO*	Hectares covered by *BORO*	ha
Crop grown – *AMAN*	Hectares covered by *AMAN*	ha
Crop grown – *AUS*	Hectares covered by *AUS*	ha
Crop grown – *MAIZE*	Hectares covered by *MAIZE*	ha
Crop grown – *WHEAT*	Hectares covered by *WHEAT*	ha
Population density	1,000s of people per grid cell	1000 people/ha
Location of 11kV and 33kV grid	Vector of grid location[3]	

Source: Vivid Economics

[3] NB, Grid data, supplied by Bangladesh Rural Electrification Board, does not include all 11 KV lines, nor any of the 400 V lines in the country.

2.3 Additional factors displayed in the tool

Among the supply factors are elements which are not directly included in the SIP attractiveness score, but have been highlighted in the tool on page 6 – '*potential exclusion zone*'. These are listed in Table 3 below. The Food and Agricultural Organisation (FAO) advise that water with arsenic levels above 100 micrograms per litre are not suitable for irrigation. Additionally, very saline soils decrease the feasibility of agriculture, and areas with greater than 30% of the area under a high saline status should be excluded. Elevation may matter as flood risks are greater in low lying areas. Finally, slopes above 8% are very costly to irrigate, and so the degree of slope should be taken into account. These factors have not been directly included in the score because we believe that they are already indirectly considered in other factors that influence the demand for SIPs. However, given the important of these factors for decision making around SIP roll out and their potential to necessitate exclusion of specific sites, we have included a visualisation of these factors in the tool.

The tool is overlaid onto a background map of Bangladesh. This provides useful navigation of the potential sites but is not part of any economic estimations. This allows developers to consider the location of the identified sites and the ease of access.

Table 3 Exclusion Factors which can be enabled in the '*SIP Site Prioritisation Tool'*

Variable	Description	Unit
Arsenic	Concentration of arsenic in groundwater	microgram/litre
Salinity	Share of area with high salinity	%
Slope	Mean slope of grid cell	%
Elevation	Mean elevation of grid cell above sea level	m

Source: Vivid Economics

2.4 Construction of 'alternative condition' scenarios

The baseline scenario view is not enough to consider where SIPs may be suitable, in the sense of being *economically*, as well as technically, viable. For this reason, the tool has an interactive function which allows four alternative conditions to be 'switched on', capturing other factors which will have a major determinant on the economic viability of SIPs from one region to the next. In particular:

- **An alternative cropping scenario:** This is particularly important, since revenues are dependent on the type of crop that is grown. Anecdotal evidence from project developers suggests that farmers switching crop types after the pump is installed can represent a major revenue risk. For example, facing decreases in the *BORO* price, a staple crop with high irrigation needs, some farmers appear to have switched to growing *maize*, which has lower irrigation needs.

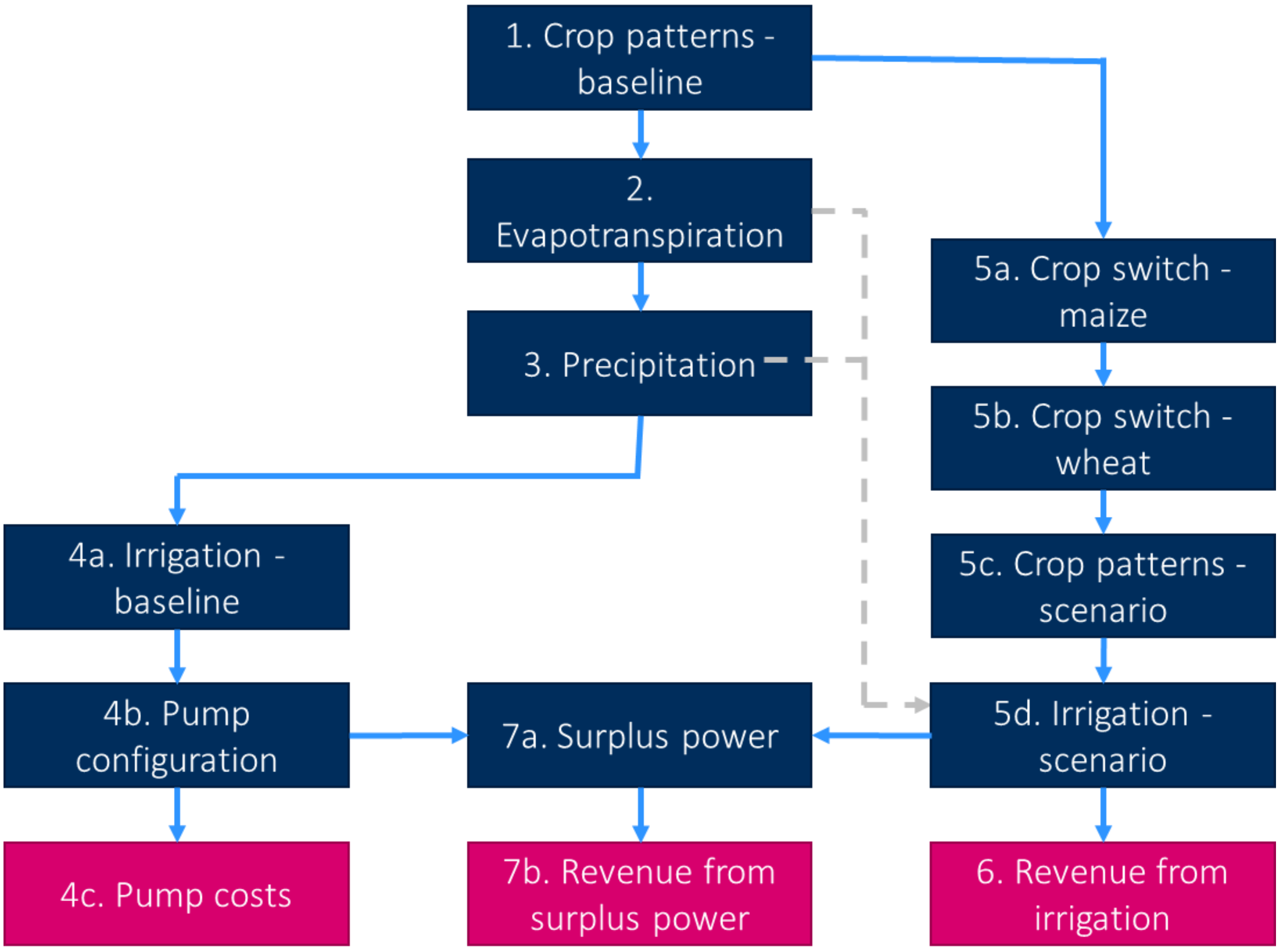
  The tool captures crop switching by allowing the user to select scenarios where a proportion of current *BORO* cultivation is switched to a combination of *maize* and *wheat*, based on a measure of the suitability of the area for each respective crop. The focus is on this downside risk, which is most relevant in this context.

- **An alternative price at which surplus energy can be sold to the main grid:** This is discussed in more details in later sections of this policy brief. A higher tariff increases the economic feasibility of pumps, if they can be connected to the grid.

- **An alternative price of irrigation per crop type, away from current IDCOL guidelines.** At a higher price, the demand level is higher, increasing economic feasibility of the pumps. Care must be taken however to ensure that prices do not push potential customers away from using irrigation.
- **Reduced costs of installing SIPs:** This allows developers to consider the changes in technology which may improve the economic feasibility in coming years.

The structure of the relevant section of the underlying model is set-out in Figure 1 below, indicating how the irrigation needs are mapped to irrigation revenues and pump costs, and how surplus power is estimated as a result.

Figure 1 Tool Overview



Source: Vivid Economics

2.5 Limitations and Caveats

The tool displays some exclusion factors, as set out in section 2.3, which are not explicit in the measure of SIP feasibility. These factors include slope, which affects the cost of supplying a pump, and arsenic and salinity, which affect the quality of water produced by a pump.

Despite the large amount of data collected and incorporated into the tool, some critical factors were not included due to lack of available data. These would need to be considered by any developer prior to installing a pump:

- **Flood Risk.** The slope and elevation are reasonable proxies for flood risk, but local conditions will also affect this. Using the tool alone will not capture the full set of local conditions. Developers should consider this risk, and the feasibility of avoiding it by raising the height of a SIP mount.
- **Groundwater stress.** The development of SIPs should shift irrigation away from diesel towards solar powered irrigation. However, in some areas, there is groundwater stress that may mean that any type of additional irrigation is problematic. Prospective SIP developers or funders should consult the 2018 Groundwater Management Act and study the local aquifer conditions to ensure this stress is being managed. The stress may vary both between aquifers and over the course of the year.
- **Size of pumps.** The tool assumes a standardised SIP of 25kWp capacity. In fact, in a given area, it may be more or less cost effective to build a few small SIPs or one large SIPs. The conditions that create this need to be taken into account.
- **Competition.** The tool assumes that SIPs are a direct substitute for diesel pumps, and that by introducing SIPs, the developers are facing no risk that they will be unable to gain customers. The model assumes a three-year transition to full demand. If irrigation prices are incorrectly set, this assumption may not prove true. Additionally, the arrival of electricity in an area could foster competition from electric pump providers, dependant on the local tariffs.
- **Electric Pumps.** The tool considers the potential of grid access, without taking into account the risk of increased competition from electric pumps if the grid arrives in a village. The presence of the grid may encourage electric pump providers, benefitting from supported electricity prices for irrigation. Policy should take this possibility into account.
- **Grid cell size.** The analysis is conducted for every 2km^2 in Bangladesh. There could be spill overs between cells in the model that mean one pump could serve two or more grid cells.
- **Data aggregation.** Much of the data is not available at the low levels of spatial aggregation displayed in the tool. For example, the crop yields data is at the district level, and therefore assumptions are made that all cells within a district produce crops according to the same patterns, conditional of the share of land under agriculture. This leads to sharp changes in feasibility at district boundaries. Local crop patterns should be verified before any decisions are made.
- **100% sell back to grid.** The scenarios consider the potential surplus electricity that can be sold to local populations or the grid. This is under the assumption that 100% of all surplus electricity is sold on, whereas in reality there may be limitations imposed. Any limitations would reduce the monthly sale of surplus electricity to the grid and reduce the attractiveness of each cell using this technology.

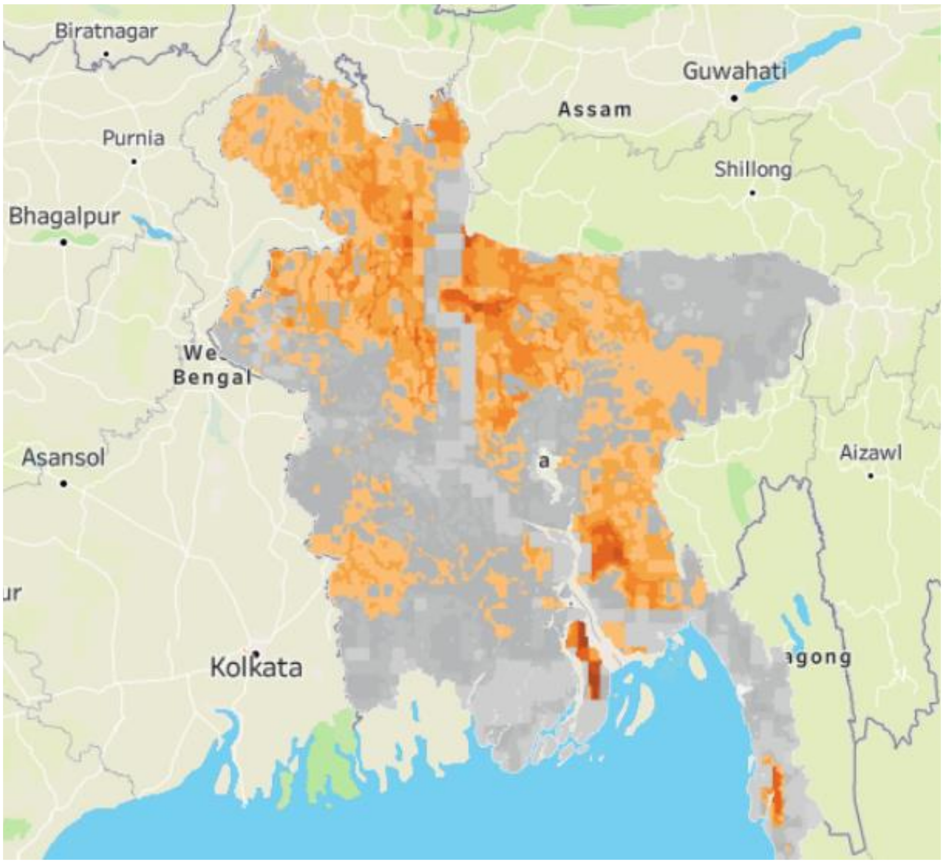
The core assumptions in the tool are documented in in Annex 3.

3 Prioritising the roll out of SIPs in the most advantageous regions

3.1 SIPs have high technical potential, with the North West being the most attractive region for SIP roll out nationwide

The most attractive regions for SIP development are concentrated in the North West, however 72 out of 80 Palli Biddut Samiti regions (PBS) nationwide could host at least one SIP. The feasibility of sites is assessed using both the demand and cost factors, which creates an attractiveness score from 0 – 10. The top locations for deployment of SIPs are concentrated in the North West of the country. This is due to a combination of large agricultural demand, with triple cropping patterns and rice cultivation, accessible groundwater, and high solar availability. Other attractive locations include the west and South Central region, with the latter being driven by high *BORO* production. It is worth noting the high flood risk in the low-lying south of the country, and the presence of saline soils, neither of which are captured in the economic assessment.

Figure 2 The most attractive regions for solar irrigation pumps are the north west and north east, although almost all regions of Bangladesh have technical potential for SIPs



Note: Light grey represents the least attractive locations for solar irrigation pumps, while orange through to darker red represent relatively more attractive regions.

Source: Vivid Economics and PwC

To meet the total irrigation demand nationwide, up to 110,000 SIPs could be built nationwide, however not all of these would be technically or economically desirable, as the potential to generate revenue and the costs of

deploying SIPs vary by location. Some of them would be in areas with deep groundwater, or little solar availability, limiting the potential for solar power to provide the irrigation needs. The feasibility scores control for these conditions, allowing sites to be ranked. Other factors, such as areas of steep slope or with high levels of arsenic in the groundwater, should be directly considered by developers.

To achieve the ambition of reaching 25,000 SIPs in the next five years, the tool shows that this could be achieved by focussing on a few priority regions with a high density of SIP potential. As shown in Figure 3 below, the policy ambition of 25,000 SIIPs could be achieved in a concentrated belt across the north west, and a smaller concentration in the north east. Patuakhali would be the centre of SIP development, with over 3,000 SIPs built in this PBS. This is driven by the *BORO* rice growing potential of the southern region of Barisal, however it should be noted that this area is subject to considerable flood risk and salinity risks. A further 17 PBS could potentially host over 500 SIPs each.

Figure 3 To reach 25,000 SIPs, the most attractive sites would be concentrated in Patuakhali.

Note: Calculated using the cumulative sum of SIP potential across all cells nationwide, until the threshold of 25,000 was reached.

Source: Vivid Economics and PwC

3.2 Policy will need to ensure the integrity of business models in each region and encourage commercial finance

As the SIP market begins to scale-up a number of different business models are emerging – each of which will play an important role in unlocking the full market potential. While to date, the vast majority of SIPs have been deployed using IDCOL's fixed financing programme of 50% grant, 35% concessional loans, and 15% equity from project sponsors, it is not anticipated that this same financing structure could serve the full market if 25,000 pumps are indeed to be deployed. This will require two developments, described in turn below.

First, the IDCOL financing structure will need to evolve to increase the share of private sector finance. It is unlikely that there will be enough grant finance to continue to support 50% of project costs, and continue to support 35% concessional loans.

Second, other financiers are likely to enter / scale up their operations in the market. In particular:

- The Bangladesh Rural Electrification Board (BREB) is deploying 2,000 solar irrigation pumps, with support from the Asian Development Bank (ADB). The business model to deploy these pumps is under development, and while it may be similar to the IDCOL structure, it will not be identical.
- The Bangladesh Agriculture Development Council (BADC) has a mandate to install SIPs. It does so as a government led initiative, and is highly subsidised, with 70% of the cost of deploying SIPs supported through a grant, and only 30% recovered from fees paid by farmers.
- Project developers are also exploring opportunities with commercial banks, and while this market has not yet developed, local commercial finance should play a role to unlock full market potential in the future.

With multiple business models emerging to serve the market, each with a differing degree of commercial, concessional and grant finance, it is important that the integrity of each of these models is preserved. Specifically, the best placed business model should be able to serve a distinct geographic market without competing with other (more concessional) business models. This is crucial to ensure that where a higher degree of private sector finance is feasible and can be supported through payments be end users, this market is not “spoiled” by the presence of heavily subsidised SIPs in the same region. The government can play a role in coordinating the role out of each business model to ensure its integrity is maintained among its end user base, by ensuring concessional finance is targeted only to specific regions where it is most needed (based on affordability for farmers).

4 Selling surplus power from SIPs to the main grid

4.1 The solar PV panels powering SIPs currently have a large underutilised generating potential

If every one of the 110,000 potential SIPs nationwide were built, an additional 2,800 GWh of electricity per year could be generated by SIPs when the power is not being used for irrigation. This could represent an important source of renewable energy which can contribute to decarbonisation of local electricity distribution networks, in addition to the renewable energy which is used to power the solar irrigation pumps. In total, if all technical potential for solar irrigation pumps were installed, it would represent 110,000 SIPs with a total installed capacity of approximately 3 GW – that is 15% of total current installed capacity connected to the grid in Bangladesh.

However, to unlock this potential, policy will need to overcome barriers related to variability in supply from the solar irrigation pumps within a day, across seasons, and across regions. There is substantial variation in the power supply available to evacuate to the grid after irrigation uses have been met. This variation is exhibited across three dimensions:

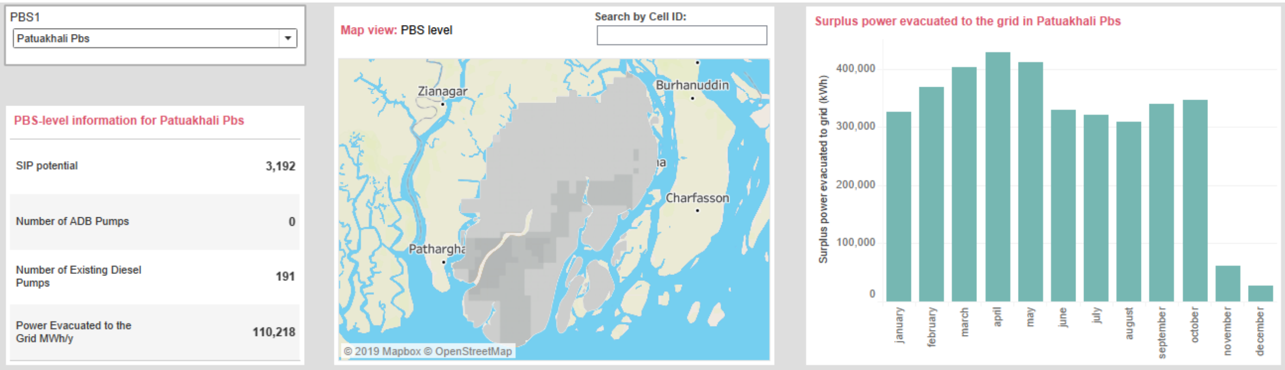
- **Across hours of the day –** without storage solutions, the solar panels will only generate power during the hours of sunlight. This problem is similar to that of conventional solar PV sources, and is not discussed in detail here.
- **Across seasons –** in particular, if the power generated by the solar PV panels is used *first* to power the irrigation pumps, then there will be very limited surplus power available for evacuation to the grid during seasons of high irrigation demand, and much more power available during seasons when the pumps are underutilised for irrigation.
- **Across regions –** the availability of power to be exported to the grid will be higher in regions where more SIPs are deployed. This may present challenges to the local grid in terms of total power evacuated, and the *'SIP Site Prioritisation Tool'* identifies how much total power from SIPs would be exported in each PBS.

Finally, the cost of connecting a SIP, or a cluster of SIPs, is not yet well understood. While from a SIP developer's perspective, any revenue generated from a SIP by sale of power to the main grid represents a boost in terms of revenue generation, this will need to be weighed carefully against the cost of connecting to and selling to the main grid. In particular, the tariffs for sale of power to the main grid will need to be determined, and the revenue generating potential compared to the cost of connecting to the grid. Only when this calculation has been made will the right decision be able to be taken not only in terms of *technical* feasibility of connecting SIPs to the main grid, but also *economic* feasibility. Specifically, there will be some SIPs that should not be connected to the main grid, where the cost of connecting to the grid would be higher than the revenue generated from the SIP, or where it would be more economically efficient to draw power for irrigation directly from the grid once that connection becomes available.

4.2 Surplus power from SIPs may pose integration challenges to grid in terms of seasonality, total power exported, and cost effectiveness

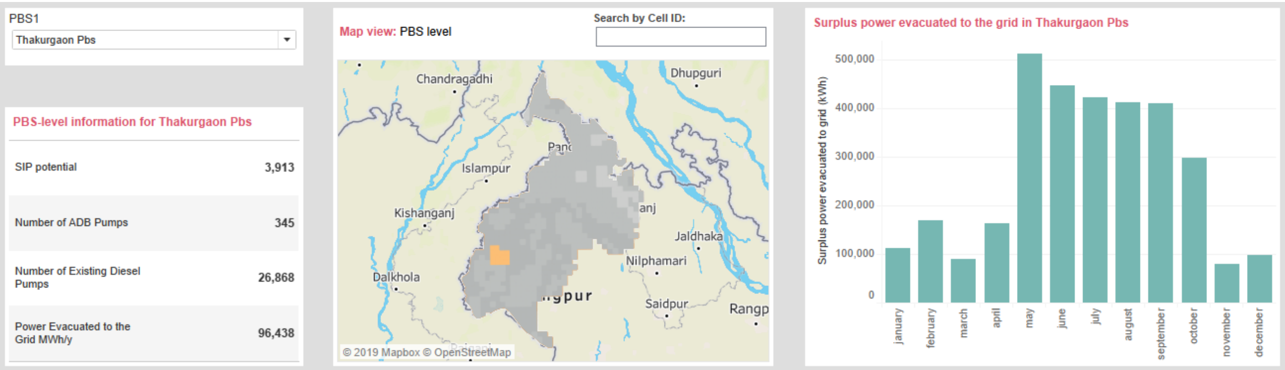
The amount of power that could be evacuated to the grid is highest in Patuakhali PBS. This is an area of high irrigation demand in the *BORO* season, and throughout the rest of the year, surplus energy could be sold to the grid. The second greatest potential is in Thakurgaon PBS, in the North West. This is an area with potentially greater feasibility once flood risk and salinity are taken into account. Figure 4 shows an example of the surplus power that can would be exported to the grid from Patuakhali PBS, and Figure 5 displays the equivalent for Thakurgaon PBS.

Figure 4 Display of surplus power evacuated to the grid, kWh per PBS, for Patuakhali PBS



Source: Vivid Economics and PwC

Figure 5 Display of surplus power evacuated to the grid, kWh per PBS, for Thakurgaon PBS



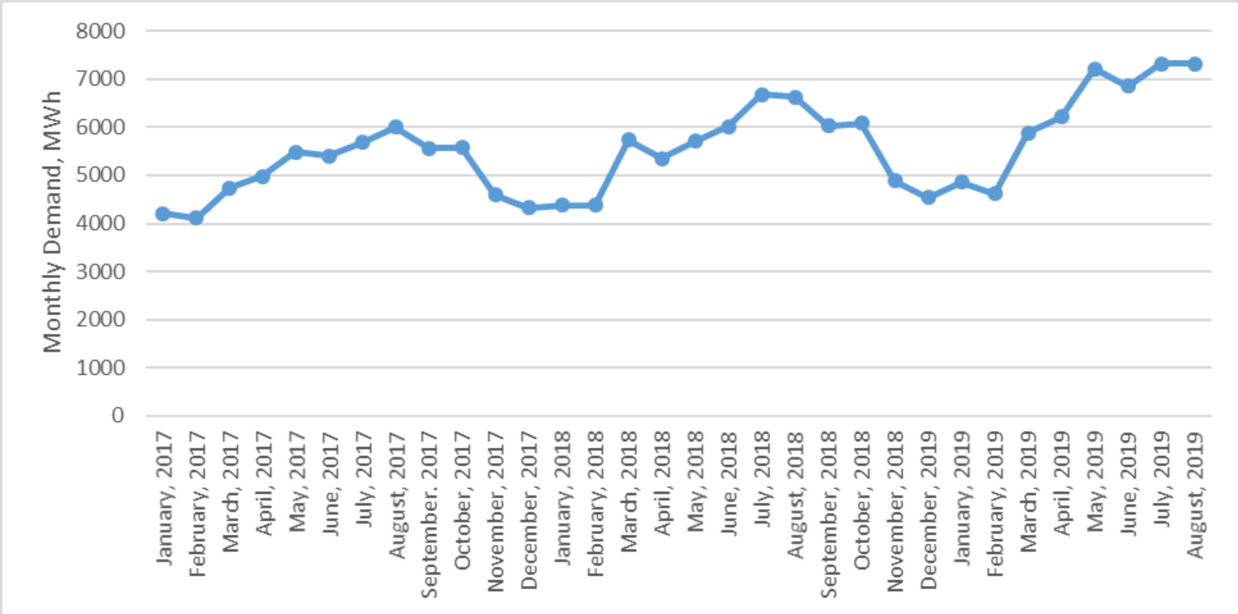
Source: Vivid Economics

There is substantial seasonal variation in the amount of surplus power for key PBS. As shown in Figure 5 in Patuakhali PBS, over 400 MWh could be evacuated to the grid in the month of May. Across January to October, this number is relatively stable, but in November and December it falls to 14% and 6% of the maximum monthly power availability. This pattern differs in each PBS; in Thakurgaon, the months of May through October provide between 300 and 500 MWh of surplus electricity, however in the months of November to April, between 15% and 33% of the power evacuated in the month of May would be available to the grid.

This seasonal variability poses a challenge for the operation of local distribution networks in that generating capacity will need to be kept in reserve to meet load across the full year. The contribution of the SIPs to meeting load (i.e. demand) is much lower for six months of the year than it is for the other six months. This means that the benefits in terms of *avoided* costs to the distribution network may be lower, as the main grid will still need to invest in generating capacity to cover the share of power that is not available from SIPs during the six months where SIPs are used primarily for providing irrigation services.

Annual peak load (i.e. demand) appears to coincide with the period when SIPs are most available to supply power to the grid. As shown in Figure 6, the period of highest demand over the last three years has typically been the summer months of April through October. As described above, and as shown in Figure 6 this corresponds to the period when SIPs are most available to evacuate power to the grid. However, the seasonal variation in the annual load curve is far less than the seasonal variation in the power available from SIPs.

Figure 6 Available surplus power from SIPs may correspond to seasons of high demand for electricity – in particular during the summer months



Source: Estimate developed based on data gathered by local consultant team from utilities.

The cost of connecting to the main grid needs to be compared to the revenue generating potential from sale of surplus power to the main grid. Only if the revenue generated from sale of surplus power exceeds the cost of connection should the SIP be connected to the main grid.

On the basis of current trials, connection of a single pump to the 11 kV distribution network is unlikely to be economically viable. At present, IDCOL is piloting one technical trial to connect a 25 kWp pump to the 11 kV distribution network. This trial demonstrates that the connection of a single pump to the 11 kV network is unlikely to be cost effective. The cost of the project is estimated to be around BDT 2 million, of which 25% relate to research and project development costs, so in the future it is expected the cost would fall to around BDT 1.5 million. This compares to a revenue generating potential, over the lifetime of a typical 25 kWp system, at a bulk tariff rate of 4.5 BDT per kWh of around BDT 1 million. This shows a sizable gap between the costs of grid connections and the revenue potential that could generate.

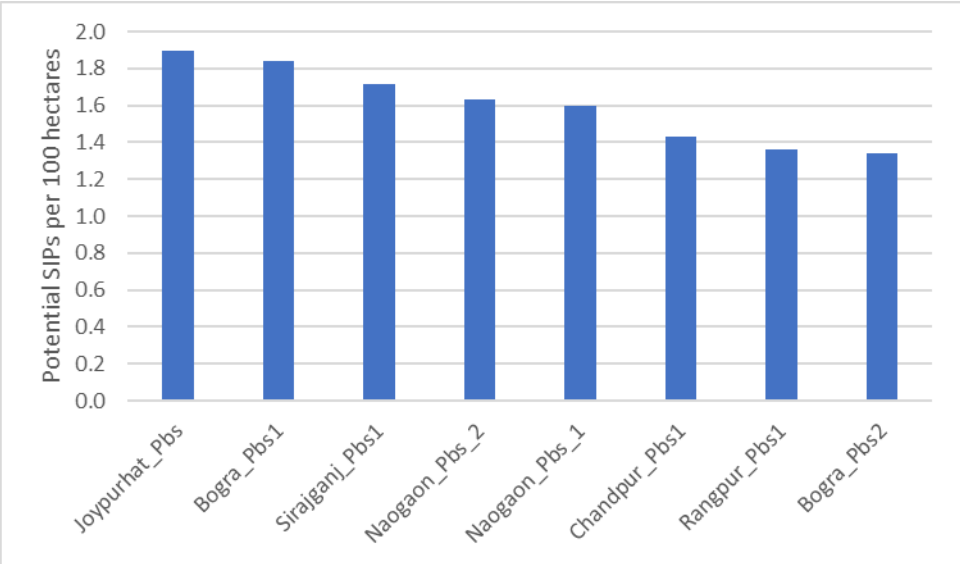
However, there are a couple of options that could make connection to the local grid and sale of surplus power economically feasible.

- **Connection to local 400 V lines should be investigated.** This should help reduce the cost of inverters and transformers required, as the cost to connect up to 400 V lines should be lower. Unfortunately, there is no nationwide mapping available of either the 11 kV lines nor the 400 V local distribution lines, so the *'SIP Site Prioritisation Tool'* is not able to identify regions where connection to the 400 V or the 11 kV distribution lines could be most economical

- **Forming a 'cluster' of SIPs should be considered, as the 'fixed' costs of connection to the grid can then be shared across multiple individual pumps.** In particular, the main infrastructure costs associated with inverters and transformers would not increase much if they are required to connect a single pump, or if they are connecting multiple pumps, as long as those multiple pumps are in a geographically compact area. Therefore, connecting an interconnected cluster of 25 kWp pumps is likely to be far more economically advantageous than connecting a single 25 kWp. Figure 7 shows the eight PBS with the highest density of potential SIPs.

Finally, policy makers need to consider the potential prices at which surplus power could be sold to the grid to ensure efficient outcomes.[4] Policy stability and transparency is important to encourage investment – so a single nationwide tariff for evacuation of surplus power to the main grid is likely to be the best option. Alternatively, prices could reflect the cost of connection on a locational basis, although this would substantially raise administrative costs to determine these locational tariffs and would reduce transparency.

Figure 7 The density of SIPs in each PBS may facilitate clusters of SIPs that can be connected to the grid, with regions of high SIP density benefitting from potential economies of scale in connections.



Note: The eight PBS with the highest density of SIP potential per hectare.
Source: Vivid Economics

4.3 Policy options include prices, quotas, and cluster policies.

Table 4 below sets out different potential policy responses to the grid connection issues raised in this report. In particular, these respond to the seasonality of surplus power potential, the cost of connecting to the grid, and the prices received by developers if this is carried out. Each of these require further potential development.

Table 4 Our approach to all tasks will build on key research and studies ongoing in parallel to the MTR 2020

Policy Issue	Policy Options
Seasonality of power availability from grid	• Restrict sale of power to be within a limited variation range – guaranteeing capacity availability • Include capacity (/availability) payments alongside unit price for sale of power • Develop storage options/alternative back up generating capacity to ensure local grid availability when SIPs not available as used for irrigation

[4] Note there also needs to be a clear policy on what happens if the grid arrives and farmers prefer to switch to using electric pumps, which would then reduce the economic viability of solar irrigation pumps, which rely on a revenue stream generated over the 20 year life of the asset

Policy Issue	Policy Options
Connection fees and per kWh pricing methodology	• Establish a single national tariff per kWh for sale of power to the grid • Alternatively, use locational pricing for unit price and/or connection fee • Consider who pays for connection of SIPs to the main grid – government grant, project developer, or local utility • Set unit tariffs per kWh based on avoided cost of installing other generating capacity
Connect to 400 V local networks, not 11 KV line – need further trials	• Trials to explore connecting to local 400 V network instead of 11 kV lines
Identify clusters, and connect only if certain conditions are met	• Consider the number of SIPs necessary to make a grid connection economically viable, and the cost of local wiring across a wider distance vs. an additional grid connection

Source: Vivid Economics

5 Accounting for uncertainty in revenue generating potential

5.1 Solar irrigation pump revenue is uncertain, and depends on actual cropping patterns

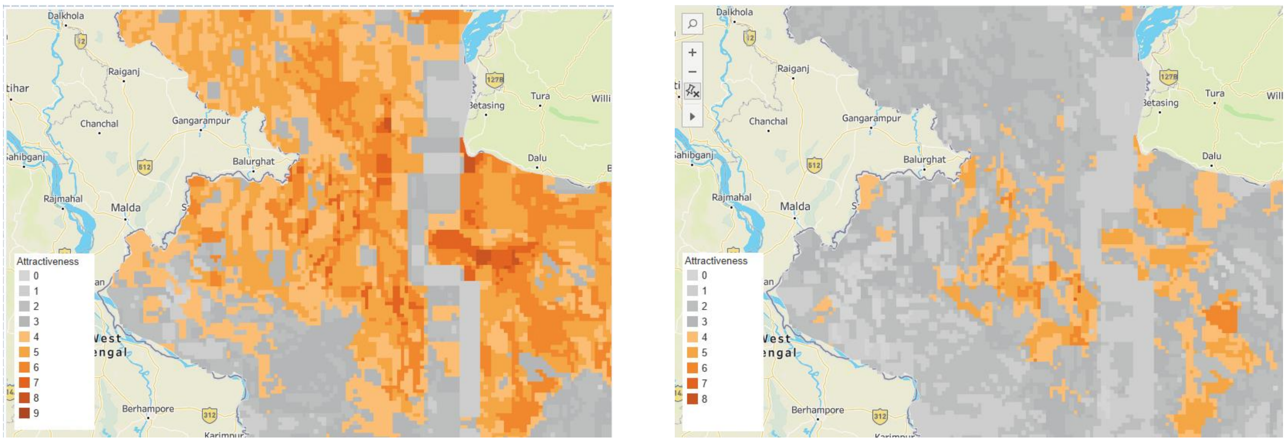
Scenarios show that as the *BORO* crop switches to *MAIZE*, the demand for irrigation decreases. This is because the irrigation requirement for *MAIZE* is lower than that for *BORO*, so the revenue generated from irrigation from the same area used for *MAIZE* is lower than the equivalent revenue that would be generated by growing *BORO.*

Anecdotal evidence from project developers suggests that farmers switching crop types after the pump is installed can represent a major revenue risk. In recent years, there have been concerns that farmers are switching away from *BORO* towards *MAIZE* as the *BORO* price falls.

The tool allows the user to select scenarios where a proportion of current *BORO* cultivation is switched to *MAIZE* or *WHEAT*, based on a measure of the suitability of the area for each respective crop. This reduces the irrigation demand, and the returns to SIPs. As a result, the feasibility of different locations falls, as can be seen in the figure below. Nationally, the total revenues from irrigation can fall by as much as 28% in this scenario, with the greatest impact in Mymensingh where revenues fall by 42%.

Crucially, while the revenue falls when farmers switch to from *BORO* to *MAIZE,* the costs do not. This is because the pump system has been designed to meet expected irrigation demand – based on the current crop coverage in the baseline. The fixed capital costs of the SIP is 'sunk' once it has been deployed and cannot be recovered, and similarly the costs of operating the pump do not reduce if the pump is less used for irrigation.

Figure 8 Comparison of priority sites in the North-West region on Bangladesh with present and alternative crop scenarios.



Present cropping patterns – majority BORO

Alternative cropping patterns – switch to MAIZE/WHEAT

Source: Vivid Economics

5.2 Policy options may include variable pricing and providing insurance to developers

Dynamic and transparent pricing can enable developers to recuperate costs even if the cropping patterns change over time. For example, the scenario that enables higher prices for selling irrigation to farmers shows higher irrigation revenues and increases the feasibility of sites. This is an option that could be used to boost feasibility. However, care must be taken to ensure farmers do not substitute away from high irrigation need crops such as BORO, or to alternate sources of irrigation such as diesel pumps or electric pumps.

Another option would be to guarantee a certain level of return to developers in areas, protecting them from price and demand risks. If an area is deemed to have high levels of feasibility, but substantial downside risk in the case of farmers switching away from *BORO*, policymakers could consider the option of securing the returns to encourage the development of sites, if that was deemed the policy priority. Additionally, wider sources of income could sustain pumps in periods of low irrigation demand. This would include the potential from grid connections, or the provision of mini grids to support the sale of surplus energy to local communities.

Annex 1: Technical Annex

The technical components that create the feasibility scores are set out in detail below. The feasibility scores were created through an excel based model using a series of tabs which refer to the raw data and other calculations carried out within the model.

5.3 Crop patterns – baseline

5.3.1 Objective

Calculates the area used for growing each main crop type during each month, based on data on the hectare coverage of five main crop types and the crop calendar. These are three types of rice, and two other crops:

- *BORO*, grown between January and April.
- *AUS*, grown between May and July.
- *AMAN*, grown between August and December.
- *MAIZE*, grown between January and April.
- *WHEAT*, grown between January and April.

The purpose is to establish the baseline expectation of crops that are grown in each region in each month. This is then used in subsequent tabs to (i) determine the size of pumping solution required, and (ii) estimate the revenue generated from irrigation services under this baseline cropping pattern.

5.3.2 Steps in calculation

- The hectare coverage of each crop type in each cell sourced from the Bangladeshi Agricultural Department's yearly data on crop patterns at a district level. These are disaggregated to the cell level according to the FAO's GeoNetwork data on share of land being cropped which is available at a 5 arc-second resolution. These create estimates of local level cropping patterns.
- The area covered by cropland for each grid cell is $2km^2$ or 400 hectares.
- Where a cell is on the border of more than one district, the cell is assumed to have a cropping pattern that is the average of the two districts.
- The average hectare coverage of each grid cell is then multiplied by the cropping calendar, which is from the Bangladesh Agricultural Department, to establish the hectares of each crop type grown in each month of the year.

5.3.3 Key assumptions made

- Crop calendar is the same throughout Bangladesh (no regional variation).
  - ◊ *BORO*, *WHEAT* and *MAIZE* are all grown in the first harvest season, between January and April.
  - ◊ Only *AUS* is grown in the second harvest season, between May and July.
  - ◊ Only *AMAN* is grown in the final cropping season, between August and December.
- Cropping patterns are homogenous on agricultural land within districts (no accurate data at a lower spatial disaggregation is available).

5.3.4 Variations by scenario

Cropping switch as discussed below

5.4 Evapotranspiration

5.4.1 Objective

Calculates crop evapotranspiration by multiplying reference evapotranspiration for each cell ETo, with crop coefficients Kc for each crop type. This gives total crop evapotranspiration, ET crop, in mm/month, for each crop, for every month of the year and every cell.

5.4.2 Steps in calculation

- Reference evapotranspiration from the FAO is derived via the FAO Penman-Monteith method,[5] and given for each cell ETo, for each month of the year. This monthly geospatial data on reference evapotranspiration in mm/month at a resolution of 5 arc-minutes was obtained from the FAO's GeoNetwork.
- Evapotranspiration for each cell, for each month in the year, is then multiplied by crop coefficients for each crop, kc.
- This gives, for every crop, a local monthly evapotranspiration number ET crop.

5.4.3 Key assumptions made

- Taking the middle value of FAO published crop coefficients for evapotranspiration.
- 30 days per month.

5.4.4 Variations by scenario

No variation.

5.5 Precipitation

5.5.1 Objective

Calculates the effective rainfall on each cell in each month, to determine how much of the irrigation requirement for each crop may be met by rainfall.

5.5.2 Steps in calculation

- Precipitation for every month of the year in mm/month, at a resolution of 5 arc-minutes, was obtained from the FAO's GeoNetwork and mapped to the grid.
- The effective rainfall is the total precipitation minus runoff, evaporation and deep percolation, giving the water that reaches the roots of the crop. The effective rainfall is estimated using FAO's formulae[6].

5.5.3 Key assumptions made

- FAO's formula on how total precipitation maps to effective rainfall.

5.5.4 Variations by scenario

No variation.

[5] http://www.fao.org/3/X0490E/x0490e06.htm#equation
[6] http://www.fao.org/3/s2022e/s2022e08.htm

5.6 Irrigation - baseline

5.6.1 Objective

This cell calculates the expected irrigation requirement in each cell, under the baseline cropping patterns. It is used to determine how much pumped irrigation is required on each cell.

5.6.2 Steps in calculation

- To calculate irrigation requirements, we follow the approach in the Peace Corps Irrigation Reference Manual,[7] which uses reference evapotranspiration and crop coefficients, area*(ET crop - effective rainfall). ET crop and effective rainfall have been calculated in the two previous tabs.
- This tab nets of effective rainfall, i.e. is *'W2. Evapotranspiration'* minus *'W3. precipitation'*.
- It then multiplies the resulting (crop-specific) irrigation requirement by the hectare coverage of each crop in each cell.
- Irrigation requirement for each crop is the maximum of the net irrigation need and 0. So there is no net negative irrigation requirement in any cell.
- The area under each crop was previously calculated in hectares, which are equal to 10000 square metres, while the evapotranspiration is measured in mm/month. This gives a value in ha*mm/month, or 10000*0.001m^3/month, 10m^3/month. The resulting numbers are therefore multiplied by 10 to be in m^3/month, and then using an assumption of 30 days per month, divided by 30 to give the flow in m^3/day.
- The irrigation needs are then summed across crops, leading to a total irrigation need to each cell/month pair.
- The peak irrigation need for a given cell, across all months, is then calculated. This enables the required pump capacity to be calculated in subsequent tabs. Every month's need is then expressed as a share of the peak need.

5.6.3 Key assumptions made

- This is an approximation as it is not feasible for us to account for groundwater contribution and available stored soil water.

5.6.4 Variations by scenario

No variation

5.7 Pump configuration

5.7.1 Objective

This tab uses the annual variation in irrigation requirement calculated in *'Irrigation – baseline'* to calculate the number of pump needs, and the panel size, to meet demand for irrigation in cell.

5.7.2 Steps in calculation

- First, electricity requirements to power the pump are estimated for each month in the year at the cell level.
    - ◊ Groundwater depth is fed in. This is raw data on the depth of groundwater in each cell in metres, sourced from the Bangladesh Agricultural Development Corporation, who have measurement

[7] http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0cdl--00-0----0-10-0---0---0direct-10---4-------0-0l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&a=d&c=cdl&cl=CL1.136&d=HASH013e8d1a442c5a625761db09.3.2

bore-holes throughout the country. The depth of groundwater at the borehole nearest each cell was used as the reference groundwater depth. This depth varies monthly.

- This is converted into pump requirements, defined by *"total dynamic head"* (TDH). This is calculated using data from IDCOL, which support renewable infrastructure in Bangladesh. The TDH is calculated using the maximum groundwater depth over the year, plus 1.5 metres for draw down. IDCOL then add extra length to compensate for friction loss. This ranges from 2.3-2.9m, and the model takes the maximum of these for security. Finally, an additional 1.5m are added to avoid critical situations in years when the groundwater may be lower than normal.

- For cells where surface water is available, this calculation is replaced by the IDCOL estimates of the TDH required to extract surface water.

- The average daily hydraulic load in each month [Water m^3/day * TDH m = m^4/day] is estimated by multiplying the TDH by the volume of water required per day, then multiplying by 1000 kg/m^3 (the volumetric density of water) to obtain the weight of the water pumped, and by 9.81 (m/s2), gravitational acceleration, to obtain the required energy needed in J. This is multiplied by 0.001 to convert J to kJ, and finally by 0.000277778 to convert kJ to kWh. This is the amount of energy required per day to meet irrigation demand in a given month.

- The hydraulic energy per day for each month is adjusted to expected combined pump and motor efficiency of 47.5%[8].

- Then, the solar PV panel requirements are calculated by:

  - Bringing in the average available sunshine in each month of the year, kJ/m2/day, for which the data is sourced WorldClim - Global Climate Data in kJ. Average daily solar irradiance for each month is converted from kJ to kWh/m2/day, which is equivalent to hours of peak sunshine. The capacity of a solar module is given in kWp (kilowatt peak), which is the amount of energy the module produces at peak sunshine – this calculation therefore "translates" solar irradiation into the units which will be used to denote solar module capacity.

  - Converting the solar availability into a panel size requirement is done by dividing the energy needed to meet the electrical power requirements of the pump in each month of the year (from step 1 above), by the available solar irradiance in each month (discounted to account for efficiency losses – the combined efficiency of pump and controller is assumed to be 90% as per IDCOL technical requirements). This yields the required solar PV size in kW peak.

  - The model then picks up the maximum solar PV panel size needed across all months of the year, which takes into account both irrigation needs which vary by month, and solar resource availability, which also varies by month.

  - The pump size is then calculated by assuming a pump to PV size ratio of 50%[9]. An additional 10% is added for headroom.

  - Finally, we are assuming that SIPs have a 25 kWp panel capacity, and divide the total PV capacity needed by 20 to obtain the number of panels with 25 kWp capacity required. The number of SIPs (with 10kW capacity) required corresponds to this.

Pump and motor efficiency	47.5%

[8] Assumed efficiency of 47.6% based on the minimal efficiency requirements for IDCOl, in the IDCOL Technical Standard for Solar Irrigation Pump (SIP) Projects.

[9] based on section 5.5.2 of Jude et al., 2019: TA-9267 - Roadmap to scale-up solar PV pumping in Bangladesh (2020 - 2035). The ADB report also specifies that the PV to pump size ratio of 2 is based on the main irrigation season in Bangladesh and the assumption that the pump operates for 5 hours a day. Specifically the text says: "For Bangladesh a ratio P_{PV}/P_{pump} > 1.73 for pumps operating 5 hours/day at full capacity, and > 1.83 for pumps operating 6 hours/day at full capacity. A realistic ratio for Bangladesh is set to 2 since winter is the most important irrigation season. It is important that P_{ump} is the real power delivered by the pump, which is less than its rated power."

Pump and controller efficiency	90%
PV to pump size ratio	50%

5.7.3 Key assumptions made

- TDH friction losses as for 70m bore hole.
- PV and motor efficiency of 47.5%[10].
- Pump and controller efficiency of 90%.
- Pump to PV size ratio of 50%.

5.7.4 Variations by scenario

No variation.

5.8 Lifecycle costs

5.8.1 Objective

This tab establishes the lifecycle costs of one SIP in each cell. The costs are estimated using a recent ADB report, Jude, A., Ugarte, S., Liu, Z., and Mahmud, S., 2019: 'TA-9267 - Roadmap to scale-up solar PV pumping in Bangladesh (2020 - 2035) -- Draft Roadmap report'.

5.8.2 Steps in calculation

- Using linear regressions, the costs per kW of pump size are estimated for: pump mount, the pump, the panels, the water storage, and the wiring. These linear estimates are then used to estimate the total cost of deploying a pump in each location, which vary according to the kW needed.
- These costs are split into capex and opex, and the full lifecycle costs are estimated. The same exercise is also repeated for diesel pumps for comparison.

5.8.3 Key assumptions made

- Determinants of pump costs.

5.8.4 Variations by scenario

The model can switch in different cost scenarios for each component cost line, and a scenario is established in which costs fall.

5.9 Crop switch – *MAIZE* / *WHEAT*

5.9.1 Objective

In regions suitable for *MAIZE*, we enable scenarios where farmers switch from *BORO* to *MAIZE* ***after*** a pump has been installed. This means the costs have been locked in on the basis of the baseline cropping patterns, but actual usage of the pumps may change after the pumps have been installed. A major reason for incorporating this functionality is that project developers have experienced farmers switching crop types, for example if the price of *BORO* falls they may switch to other crops, in particular *MAIZE* and *WHEAT*.

This step captures the hectare coverage of crops of each crop type once any scenario switching from *BORO* to *MAIZE* and/or *WHEAT* has been accounted for. It represents a stylised “real life” alternative where the

[10] Based on experience from previous projects financed by IDCOL

pumps have been sized based on the baseline cropping patterns, but farmers may then change these cropping patterns even after the pumps have been installed.

5.9.2 Steps in calculation

- First we draw in the proportion of each zone that is rated as *'very suitable'*, *'suitable'*, or *'moderately suitable'* to grow *MAIZE*. This proportions come from Bangladesh Agricultural Research Council, at the Upazila level. For each cell, the proportion (%) is multiplied by the total area of each grid cell ($2km^2$) to calculate the land that could be suitable for *MAIZE* or *WHEAT* cultivation.
- For each month, we then calculate the hectares that *could* switch from *BORO* to *MAIZE*, based on an assumed percentage switching, which varies for each of the three suitability types.[11]
- Switching is then modelled in sequential stages for the amount of land at each type of suitability, up to a maximum of all *BORO* switching to *MAIZE*.
    - ◊ For *AUS* and *AMAN*, these are the same as in the baseline cropping scenario.
    - ◊ For *BORO*, *MAIZE*, and *WHEAT*, this captures crop switching between January and April.

5.9.3 Key assumptions made

- *MAIZE*, *WHEAT* and b *BORO* seasons are interchangeable, so can switch easily from one crop to the other.
- Proportion of switching is a function of *'MAIZE* suitability' in that cell.

5.9.4 Variations by scenario

A scenario in which farmers switch from *BORO* to *MAIZE* and *WHEAT* is established, which has an impact on both (i) to total power used for irrigation – and therefore on surplus power available for other uses, and (ii) the revenue from irrigation, which depends on the crops grown.

[11] For example, for *'very suitable'* land we may assume 40% switches from *BORO* to *MAIZE*, while for *'suitable'* land, 30% switches, and for *'moderately suitable'* land, 5% switches

5.10 Irrigation - scenario

5.10.1 Objective

This step models the actual irrigation requirement in a scenario where farmers have changed crop patterns from the baseline cropping patterns observed. This irrigation requirement and hectare coverage is what feeds into subsequent revenue calculations of both (i) irrigation revenue (prices per crop per hectare), or from (ii) sale of surplus power (which depends on actual irrigation demand).

5.10.2 Steps in calculation

- As per irrigation in the baseline, except it now multiplies the net irrigation requirement by the hectare coverage in each cell, accounting for crop switching.

5.10.3 Key assumptions made

- None.

5.11 Revenue from water supply

5.11.1 Objective

This calculates the revenue generated per month from irrigation services, which are priced on a per season per hectare basis.

5.11.2 Steps in calculation

- Pulls up the ha irrigated for each crop and each month.
- It uses the medium IDCOL price for each crop per ha per season and the divides this value by the number of months in the season to obtain a monthly fee.
- This is then multiplied by the number of hectares irrigated for each crop and the products are summed per month to obtain an estimate of revenue.

5.11.3 Key assumptions made

- Price lists taken in indicative ranges per crop from IDCOL. It takes the same price for each crop and applies this uniformly across all regions

5.11.4 Variations by scenario

The actual hectare coverage (and charged for irrigation) depends on the crop scenario chosen.

The prices can be varied to medium (baseline), and high (scenario), which are based on the observed ranges of IDCOL prices.

5.12 Surplus energy

The objective of this step is to calculate the energy produced by the solar PV panels, which are not used to meet irrigation demand.

The size of the pump is determined in '*pump configuration*', to meet the expected baseline demand. The pump and solar PV panels are sized to meet maximum irrigation demand across the year. This means that for (at least) one month of the year the energy generated by the solar PV panels is expected to be fully utilised for the irrigation pumps, but for other months it will be under-utilised.

This step deducts the actual irrigation requirement, which may differ from the expected irrigation requirement the pump was designed to meet, as estimated on tab *'irrigation* scenario'. It deducts the monthly electrical power required to meet irrigation, from the electrical power generated by the solar PV panels.

This remaining surplus power, which varies by month, could be repurposed for other applications.

5.12.1 Steps in calculation

- Feed in electric power generated in each month from *'pump configuration'*.
- Calculate actual electrical power needed to meet irrigation demand, by converting actual irrigation requirement from tab *'irrigation* scenario' into electrical power needed (same process as described on '*pump configuration'*.
- Subtract actual electrical power to meet irrigation demand from electrical power generated. This is the surplus energy that is available for other uses.

5.12.2 Key assumptions made

- Assumes irrigation demand is always met first, and only energy generated after irrigation demand has been met is available for sale to other purposes.

5.12.3 Variations by scenario

This will be affected by the cropping scenario selected.

5.13 Non-irrigation revenue

5.13.1 Objective

This tab estimates the potential revenue generated from sale of power generated by the solar PV panels when they are not (fully) utilised to meet irrigation demand. This sale can either be to local households or to the grid.

5.13.2 Steps in calculation

- Surplus electrical power available for sale is fed through from *'surplus energy'*.
  - ◊ The surplus power is multiplied by an assumed sale price (see variation in scenarios below), accounting for loss of power from inverters and transformers.
  - ◊ The surplus power could also be sold to the local population, for which it is multiplied by an assumed sale price, up to the maximum of the number of local households and their estimated local demand.[12]

5.13.3 Key assumptions made

- All surplus power can be sold to the grid.

5.13.4 Variations by scenario

Two pricing scenarios for sale of surplus power to the main grid are incorporated. The built-in scenarios include:

- A “high” price sale of power, which is set at BDT 3.5 per kWh. This is the current price that farmers pay to purchase electricity for irrigation from the grid.
- A “medium” price of 2.5 BDT per kWh

[12] Taken from World Bank’s Energy and Poverty Special Report, March 2009, which eestimates the mean household in Bangladesh consumes 25kwH of energy per month. The 2010 HIES in Bangladesh found the mean rural household size to be 4.5 people.

Annex 2: Data Sources

Table 5 Data Sources

Description	Data sources
Grid cell ID	Vivid Economics
Mean elevation	NREL
Mean slope	NREL
33 KV line	BREB
11 KV line	BREB
River/surface water body	DIVA-GIS & NREL
Roads	Arc Bangladesh
Estimated population per cell.	Gridded population of the world
Mean daily solar radiation -- January - December	WorldClim - Global Climate Data
Mean monthly reference evapotranspiration in mm/month -- January - December	FAO GeoNetwork -- Underlying data at a resolution of 5 arc minutes.
Mean monthly precipitation in mm/month -- January - Decemver	FAO GeoNetwork -- Underlying data at a resolution of 5 arc minutes.
Mean monthly groundwater level -- January - December	Bangladesh Agricultural Development Corporation 2000 (verified using more recent data from Shamsudduha, M., at a lower spatial level)
Land cultivated for *BORO*	2016 Agricultural Yearbook
Land cultivated for *AMAN*	2016 Agricultural Yearbook
Land cultivated for *AUS*	2016 Agricultural Yearbook
Land cultivated for *MAIZE*	2016 Agricultural Yearbook
Land cultivated for *WHEAT*	2016 Agricultural Yearbook
Share of land that's cropped	Geonetwork
Percentage of soil salinity zones 1, 2, 3 and 4 in grid cell. Generally, zone 1 is very low salinity and zone 2 still relatively low also. Zones 3 and 4 are problematic.	BARC
Concentration of arsenic in water	British Geological Survey
Number of electric pumps in cell (averaged from upazilla level count)	Agriculture Department

Number of diesel pumps in cell (averaged from upazilla level count)	Agriculture Department
Number of existing solar irrigation pumps	IDCOL and SolarGAO
Planned SIPs in Bangladesh	BREB
Share of cell in suitability 1-5:1 Very Suitable 2 Suitable 3 Moderately Suitable 4 Marginally Suitable 5 Not Suitable	BARC
Share of cell in suitability 1-5:1 Very Suitable 2 Suitable 3 Moderately Suitable 4 Marginally Suitable 5 Not Suitable	BARC
Share of cell in suitability 1-5:1 Very Suitable 2 Suitable 3 Moderately Suitable 4 Marginally Suitable 5 Not Suitable	BARC

Annex 3: Core assumptions

Table 6 Core assumptions

	Baseline	Scenario	Unit
Pump configuration			
Typical size of system (panel kWp)	25	25	kWp
PV and controller efficiency	90%	90%	
Pump and motor efficiency	48%	48%	
Pump to pv size ratio	50%	50%	
Inverter efficiency	95%	95%	
Transformer efficiency	95%	95%	
Headroom	10%	10%	
Total Dynamic Head (TDH) formulae[13]			
Spare Draw Down	1.5	1.5	m
Total loss (Friction loss due to Elbo+ Intake screen + Pipe flow)	2.9	2.9	m
Avoidance of Critical Situation buffer	1.5	1.5	m
TDH for surface water	7.6	7.6	m
Crop specific irrigation prices			
BORO	2500.00	3000.00	BDT / acre/season
AMAN	800.00	1200.00	BDT / acre/season
AUS	800.00	1200.00	BDT / acre/season
MAIZE	1000.00	1250.00	BDT / acre/season
WHEAT	800.00	1200.00	BDT / acre/season
Other			
Total irrigation revenue achieved in year 1	50%		
Total irrigation revenue achieved in year 2	75%		
Percentage of electricity that can be sold to the grid	100%		
Tariff for grid connection	2.5	3.5	BDT/kWh

[13] TDH = Static Height + Static Lift + Friction Loss Static Lift is the height the water will rise before arriving at the pump

Source: Vivid Economics

Table 7 Additional Scenario Assumptions

Cropping scenario		
Share of *BORO* switching to *MAIZE* (very suitable zones)	75%	
Share of *BORO* switching to *MAIZE* (suitable zones)	50%	
Share of *BORO* switching to *MAIZE* (moderately suitable zones)	10%	
Share of *BORO* switching to *WHEAT* (very suitable zones)	20%	
Share of *BORO* switching to *WHEAT* (suitable zones)	10%	
Share of *BORO* switching to *WHEAT* (moderately suitable zones)	5%	
Modelled reduction in costs		
Pumping system	42%	
PV module	42%	
Controllers	42%	

Source: Vivid Economics

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Vivid Economics Company profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organizations.

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