Modelling Decentralized Renewable Energy Systems

Modelling of DRE at Health Facility- Level

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Model Scope and Boundary

The model was set up in order to address the below question.

Question the Model Should Address: Which is the most cost-efficient and reliable limeans of supply of electricity for the facility under different contexts: 1) Good Grid Connectivity available, 2) Grid Connectivity unreliable.

Additionally, it was desired that the model be flexible enough so as to be used by the below user types:

Type 1: The model user is someone who is in charge of a single healthcare facility - in terms of taking decisions about the energy systems at the health facility itself .

Type 2: The model user is a higher level official, possibly a state level official, who is in charge of multiple health facilities. (Time Bound- Ministers and Officers)

Type 3: The model user is someone in charge of decisions related to both energy and health at the state or country level. (Creating Budget- WHO, Finance Ministries)

In response to the above requirements, the model scope is described below.

Model Boundary

Geographical Boundary: Health Facility.

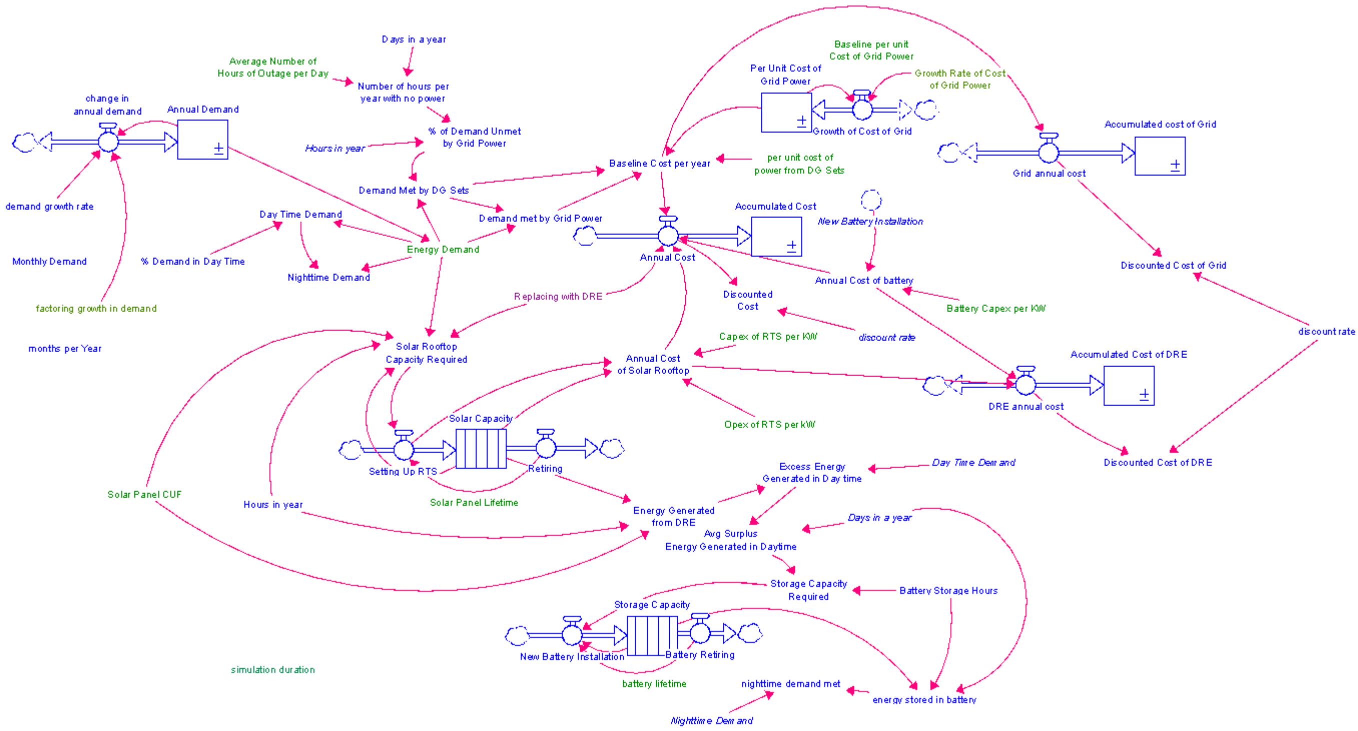
Time Horizon: 2-30 Years (Flexible).

Time Step: Annual

The simulation model is capable of generating 'what-if' scenarios of different systems of energy supply (grid and 100% DRE), along with the cost and reliability implications. The Model is able to compare different systems of energy supply in terms of their relative costs and reliability under the conditions described above. To be relevant for the 3 user-types described, the model has inbuilt flexibility to change the demand of electricity (to represent for eg. multiple facilities) and the time horizons (say 2 years for a person in charge of 1 facility to 25-30 years to someone in charge of policy-level decisions at a higher level).

The model is able to run scenarios simulating the impact of contingencies such as lower Capacity Utilization, and changes in costs, etc.

Model Structure and Logic



High Level Model Structure

The model consists of 1) The energy demand, 2) The energy supply technology – grid with backup power or DRE (Solar rooftop integrated with battery storage), and 3) The associated costs, which are comprised of Capex and Opex. The model responds to the key question of which is a cheaper supply option between Grid and DRE over time, and in what context, taking a case of a healthcare system. The model can generate scenarios for a baseline with grid and do comparative runs with replacing the energy delivery system to DRE. This generates runs over a 2 year to 30-year horizon on the relative characteristics and costs of the two energy delivery mechanisms. The model can test the implications of different scenarios and contexts, e.g., Compare costs of electricity supply from DRE and Grid over the simulation time under different extents of outages, varying DRE CUFs, different costs of grid and backup power, and DRE technology, i.e., solar panels and batteries, etc. A snapshot of the model is given above.

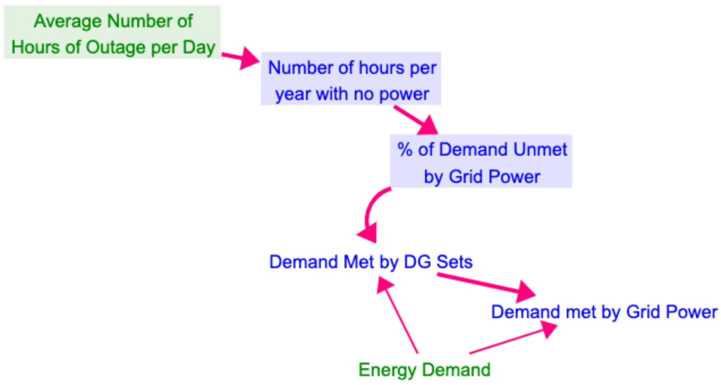
Model Boundary: Healthcare Facility

Temporal Horizon: 2-30 Years (Specified by the user)

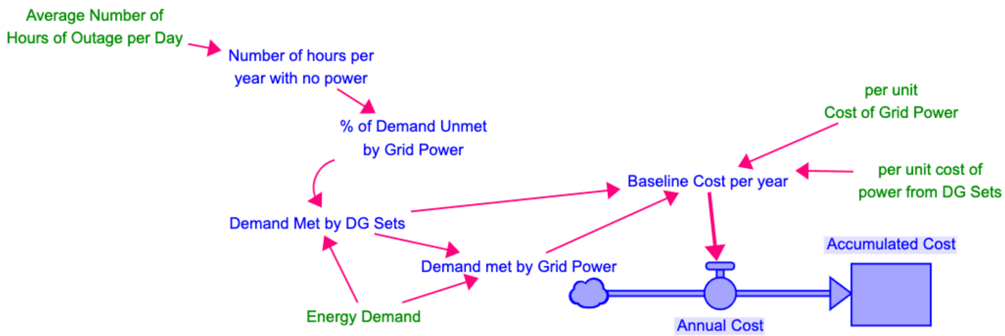
Temporal Resolution: Annual .

Below the overall model logic for the DRE Simulation model is presented, in a step-by-step unfolding manner. Variables in green are user inputs which can be changed through the model interface linked here.

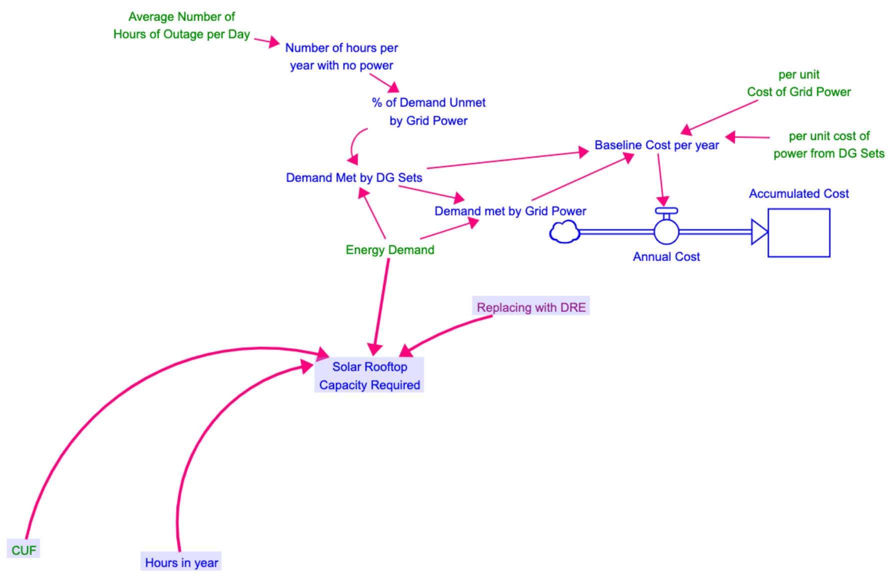
The model logic can be understood by beginning with the energy demand for the healthcare facility. The demand is input by the user. In a baseline scenario, a % of the demand is met by the grid and the remainder by DG sets. This depends on the hours of outages specified per day, a user input.



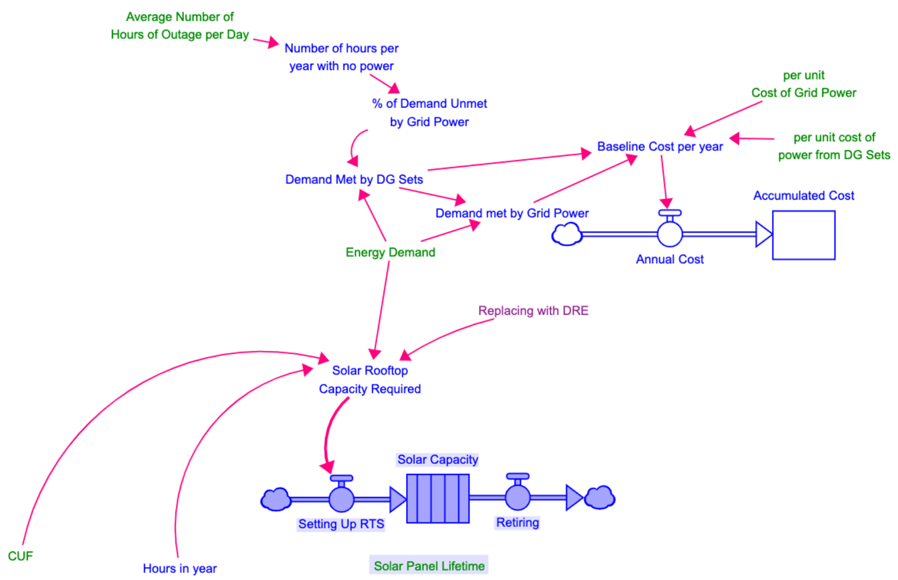
The cost of power in the baseline case is determined using the units of power serviced by the grid and by the DG set and the respective costs per unit of each, all specified by the user. This gives the annual costs, which also accrues in a stock of accumulated cost, giving the cumulative cost of power over the years.



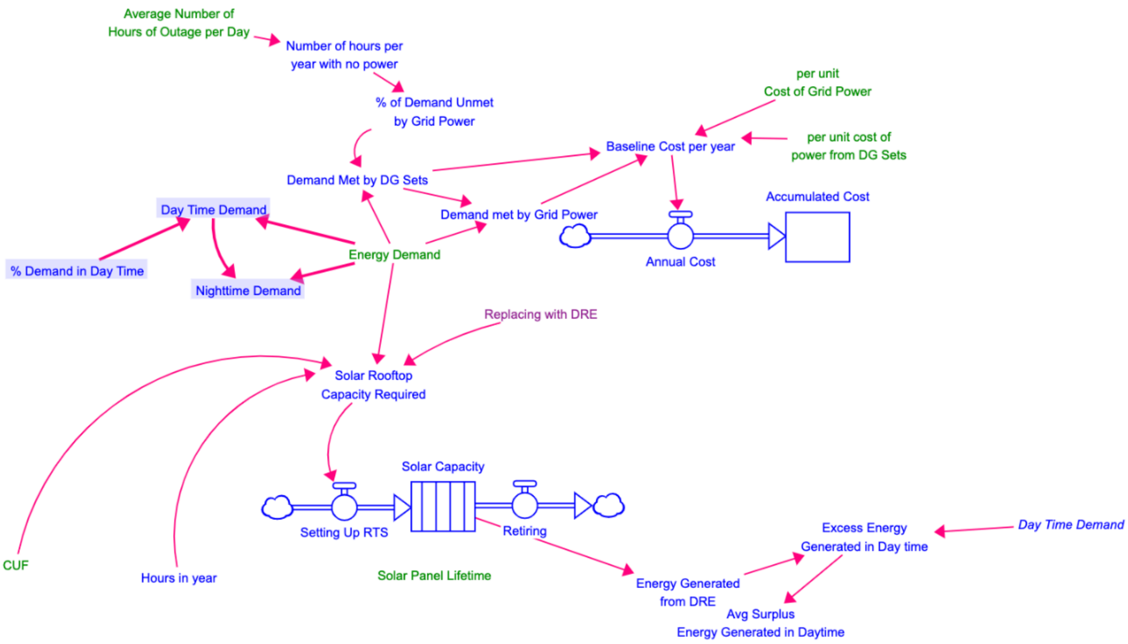
In a scenario where we replace the energy supply with a DRE system in the form of a solar rooftop-battery system, the model aims to meet the entire demand through 100% DRE. It first computes the capacity of solar rooftop required in order to meet all of the demand. This is computed using the expected CUF of solar (A user input) and the demand to be serviced .



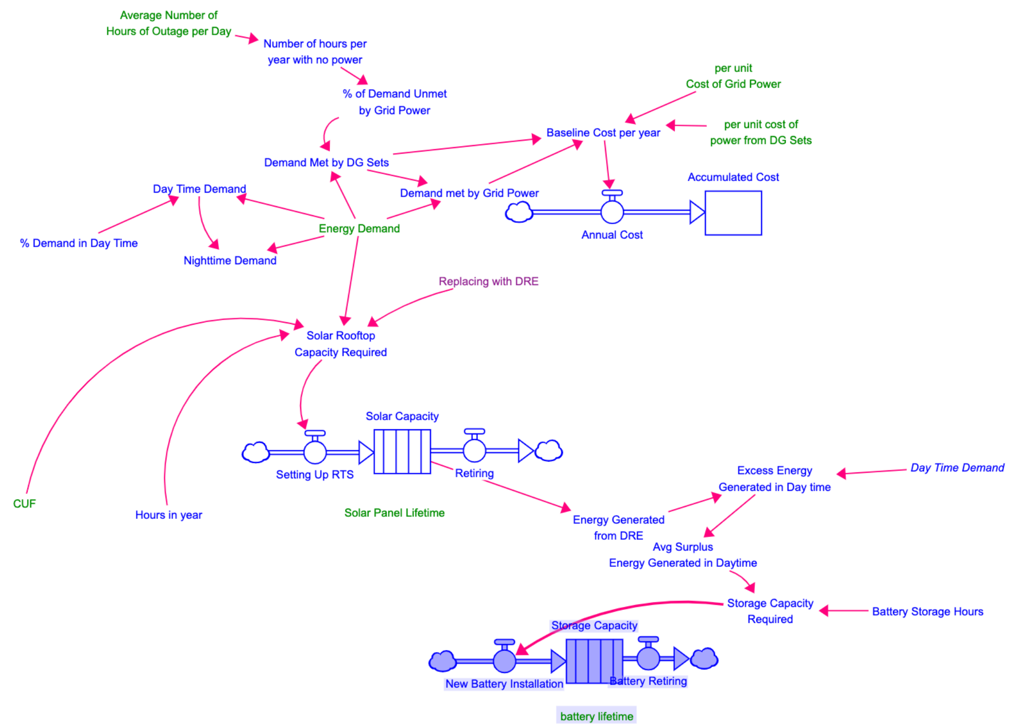
The model then installs the required capacity of solar panels in order to meet the demand. This capacity comes online and stays online as the stock of total onboard solar capacity for its lifetime (Lifetime is also a user input).



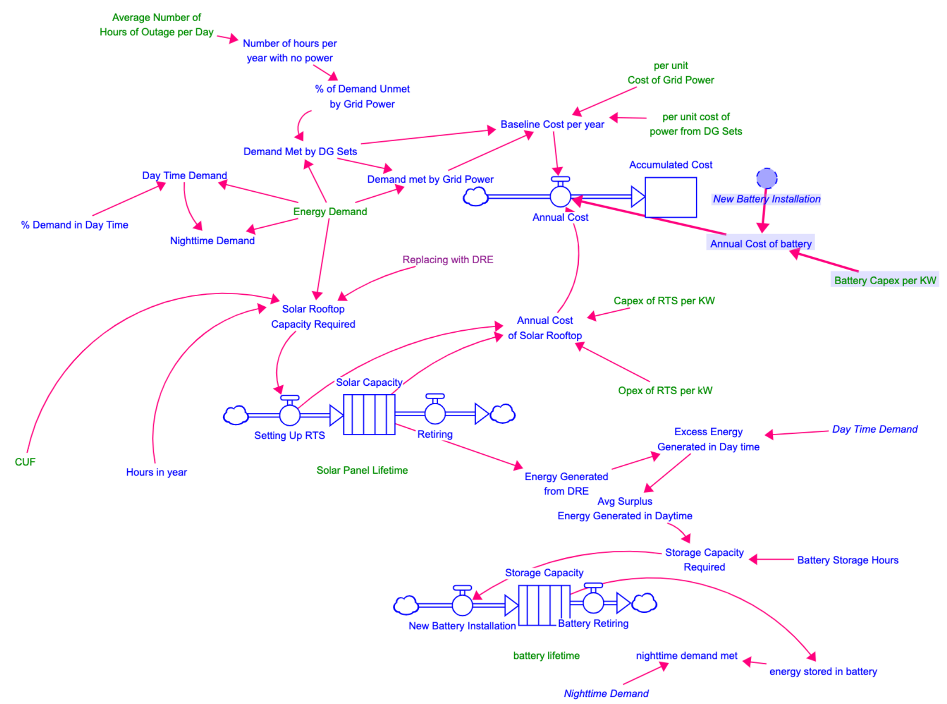
In order to have a 100% round-the-clock DRE system, the daytime/night time aspect of solar power generated must be accounted for, to determine the required battery storage. This is achieved by splitting the demand into day and night time demand (a 50-50 split is input as a assumption). For 100% DRE round-the-clock, the solar generation during the day must exceed the day time demand and the surplus energy stored in a battery storage system to service the night time demand, and the surplus energy generated must at least equal the night time demand. By subtracting the day time demand from the solar energy generated, the model computes the surplus energy which can be stored in a battery system. This stored energy then is used to meet the night time demand.



The capacity of the battery storage system required to be brought online is determined by the average surplus energy generated (scaled down from annual to per day values) and the battery storage hours (Storage duration). This determines the battery storage capacity that must be installed. This capacity is installed and comes online as a stock of battery storage online. This stays online until the lifetime of the batteries (which is a user input).



The cost of the DRE system is computed using the capex and opex of the solar rooftop system. Capex times the new installation gives the capital cost and the opex times the online capacity gives the opex per year. These accrue in a stock of total accumulated cost over time to give the cumulative cost. The battery capex is also accounted for, at the time of installation and then every time the battery is replaced (according to its lifetime).



In this way, the model is able to compare the baseline case of a grid -based power supply and a DRE-based energy supply.

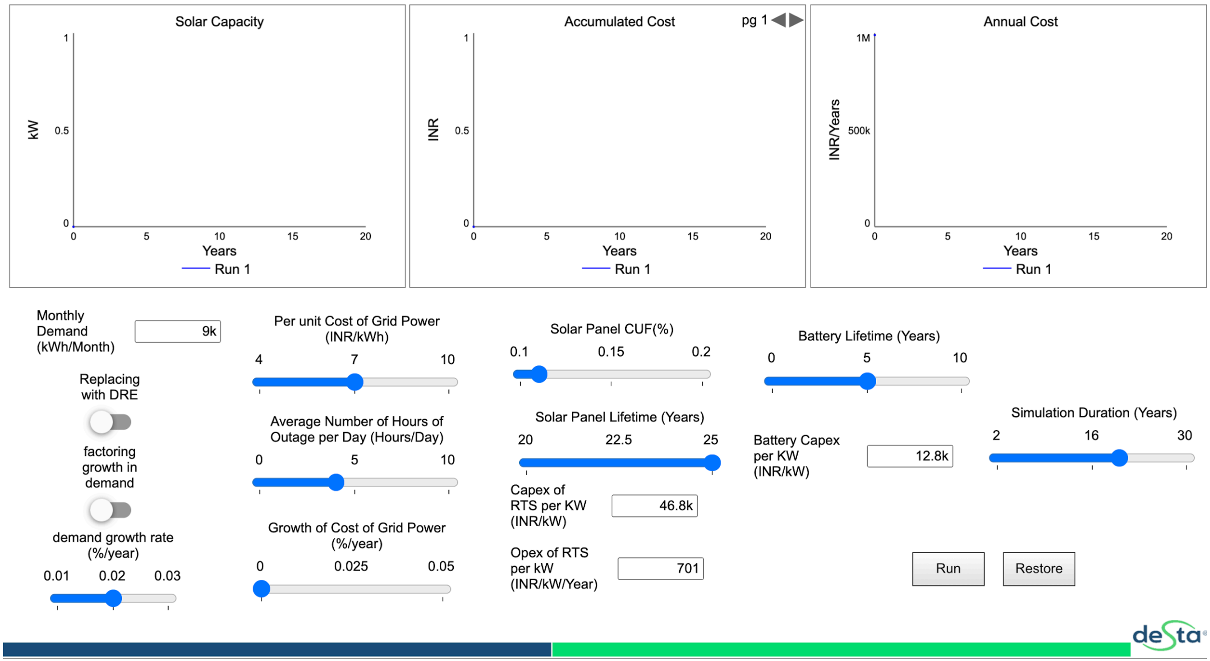
Model Parameters

Parameter	Value	Units	Source
Monthly Demand of Healthcare Facility	9000	kWh/Month	SELCO Foundation
Per unit Cost of Power for Health Facility from the Grid	7	INR/kWh	https://www.downtoearth.org.in/blog/energy/decentralised-renewable-energy-solutions-offer-great-promises-for-healthcare-facilities-79589
Per Unit Cost of Power from Backup Power Source (DG Sets)	20	INR/kWh	https://powerline.net.in/2022/01/08/cost-economics-4/
Average Number of Outage per Day (Grid)	4	Hours/Day	Assumed.
Capex of Solar Rooftop	46,755	INR/kW	Derived from SELCO Foundation Data
Opex of Solar Rooftop per Year	701	INR/kW/Year	Derived from SELCO Foundation Data
Capex of Battery Storage	12,832	INR/kW	Derived from SELCO Foundation Data
Solar Capacity Utilization Factor	0.11	Unitless	Derived from SELCO Foundation Data.
Solar Panel Lifetime	25	Years	https://www.forbes.com/home-improvement/solar/how-long-do-solar-panels-last/
Battery Lifetime	5	Years	SELCO Foundation Data
Battery Storage Hours	4	Hours	https://energy.prayaspune.org/our-work/research-report/estimating-the-cost-of-grid-scale-lithium-ion-battery-storage-in-india
% Energy Demand Falling in Day Time	50%	Unitless	Assumed.
Baseline Growth in Demand	0%	Per Year	NA
Baseline Growth of Cost of Grid Power	0%	Per Year	NA

Model Interface

The model interface, shown below is the platform that a user can use to access the model, change inputs and generate scenarios. It can be accessed through a web browser, linked here.

Model Interface



Key Output Indicators

1. Solar Capacity Installed
2. Accumulated Cost
3. Annual Cost

Levers/Switches Available to the User to Generate Scenarios

1. Demand (kWh/Month)
2. Per unit cost of Grid Power (INR/kWh)
3. Average Number of Outage Hours per Day. (Hours/Day)
4. Growth of Cost of Grid Power (%/Year)
5. Growth Rate of Demand (%/Year)
6. Solar Rooftop CUF. (%)
7. Solar Panel Lifetime (Years)
8. Capex of RTS (INR/kW)
9. Opex of RTS (INR/kW/Year)
10. Battery Lifetime

11. Battery Capex per kW (INR/kW)
12. Simulation Duration (Years).

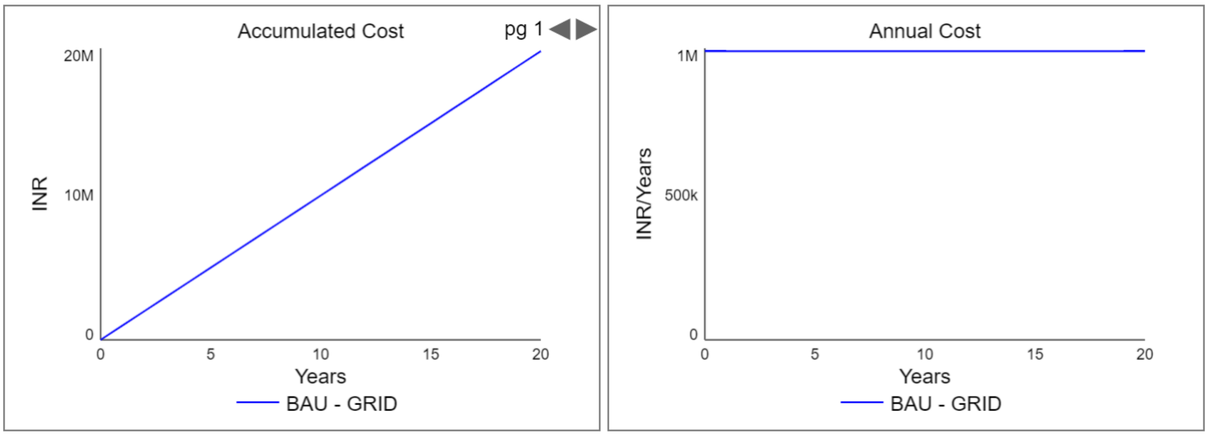
Questions the Model can Answer

1. Which is a cheaper supply option between DRE and Grid, and how the costs pan out over time, under
    a. short and long term durations and
    b. under different cost and technical specifications and
    c. under different scenarios of growth of demand and growth in cost of grid power.
2. Under what conditions does DRE become cheaper than grid and vice-versa
3. In how many years does the cross over between Grid and DRE happen
4. What is the sensitivity of different parameters on the costs for both.

The model is essentially set up to allow users to generate their own scenarios and appraise themselves of the outcomes. Some illustrative scenarios the model can generate are given below.

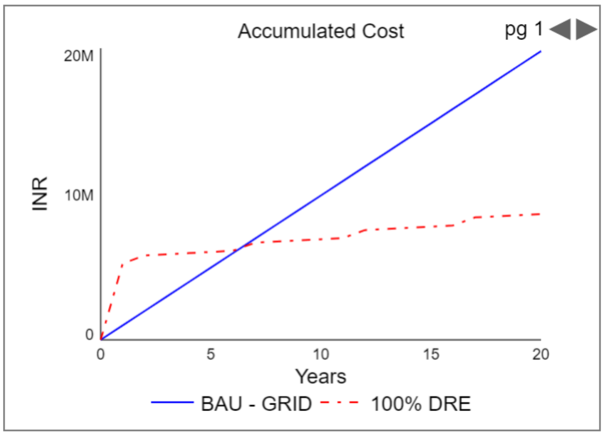
Illustrative Scenarios

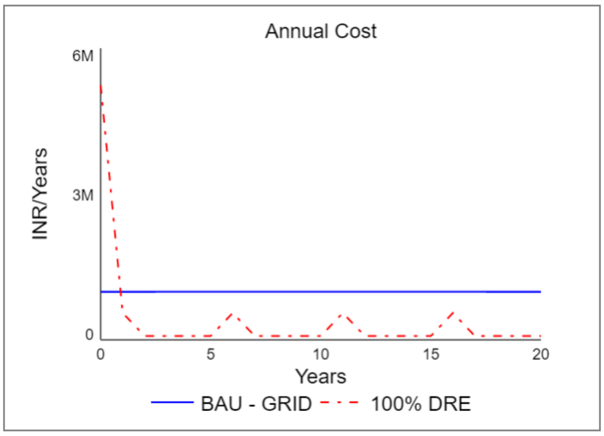
Scenario 1: Business as Usual Scenario – Unreliable Grid

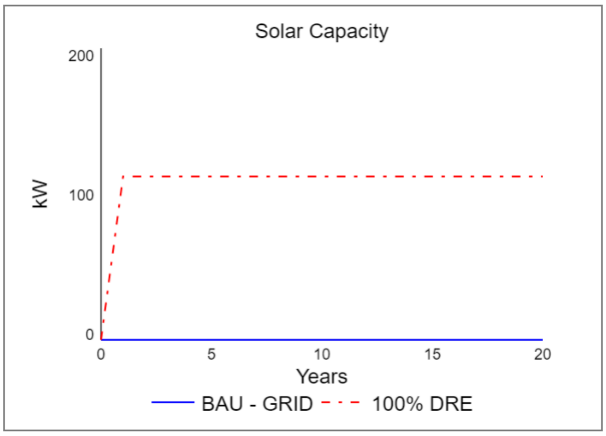


In the Business As Usual Scenario (BAU) we simulate the costs of an unreliable grid (having 4 hours of outages per day) at a cost of INR 7/kwh. This results in an annual cost of INR 1 million, accumulating to INR 20 million for a 20-year time duration. The demand is kept constant at 9000 kwh/month.

Scenario 2: 100% DRE Scenario

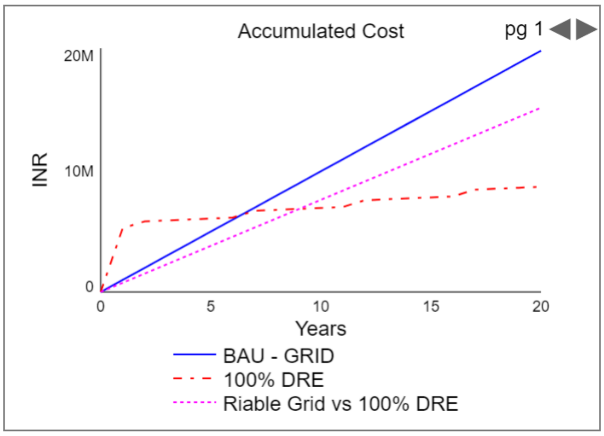


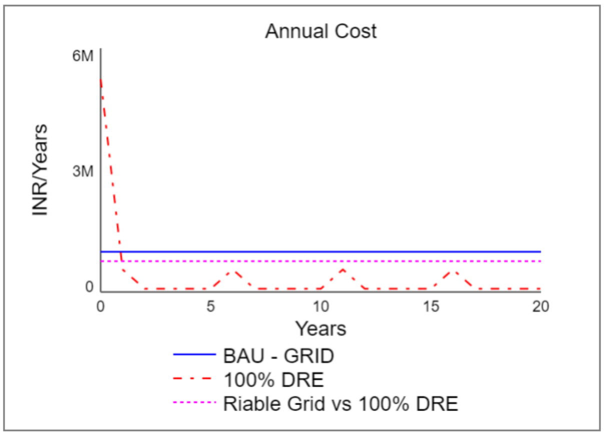




Here we simulate a 100% grid replacement scenario. The entire demand is met by Decentralized Renewable Energy (DRE) system. In order to meet the demand, it requires 112 KW of solar installed capacity which, at a Capacity Utilization Factor (CUF) of 11% can generate enough power to meet the demand year-round. The system also has storage (battery) costs of INR 4,75,000/- which is a recurring expenditure every 5 years. Hence the initial capital cost of the system is INR 5.24 million with an accumulated cost of INR 8.63 million over 20 years. This proves to be a cheaper alternative compared with the Grid accumulated cost of INR 20 million. The cross over in the accumulated cost between Grid and DRE happen in around 7 years. This is so because the DRE system has an upfront heavy capital cost but due to lower recurring costs it proves to be cheaper than the Grid from the 7th year onwards.

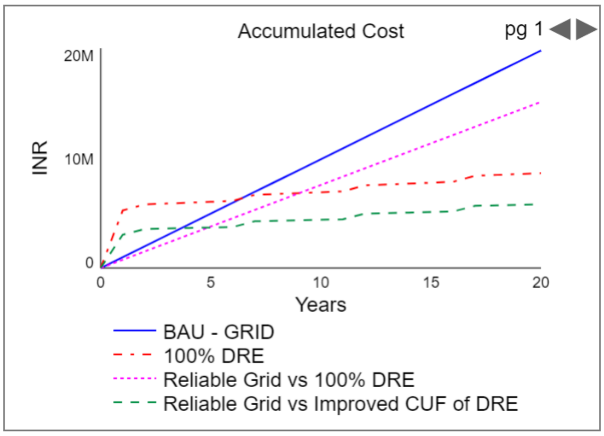
Scenario 3: Reliable Grid (no outages) vs 100% DRE Scenario

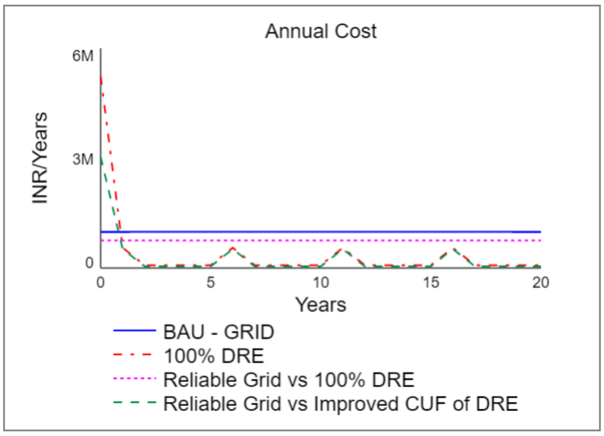


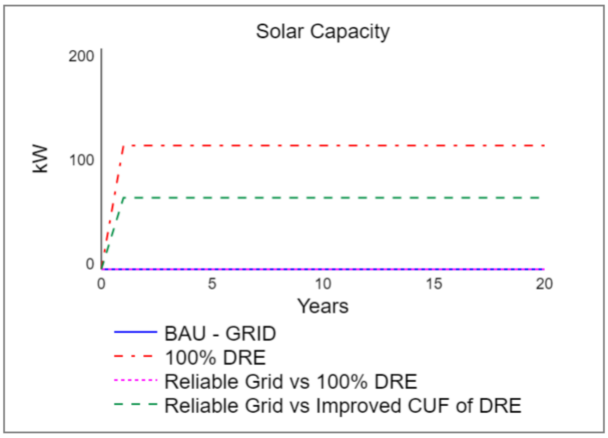


In this scenario we make the grid more reliable i.e. Zero outages per day, to compare it with a 100% replacement with DRE. As can be seen the accumulated and annual cost of Grid does come down from the BAU scenario but is still more costly than the DRE system. The cross over between accumulated costs of Grid and DRE now happens at 9 years as compared to the earlier scenario of 7 years. Hence, even with a reliable grid DRE system is a cheaper alternative in the long run.

Scenario 4: Reliable Grid vs Improved CUF of DRE







In this scenario, we simulate the best case for DRE by increasing the Capacity Utilization Factor from the existing 11% to the maximum of 20%. With this, the DRE becomes even more efficient and cost effective. The capital cost comes down to INR 2.88 million as compared to INR 5.24 million since the Solar PV installation capacity is now reduced by close to 50% down to 61 KW from an earlier value of 112 KW. The total accumulated cost of DRE over 20 years comes to INR 5.6 million. The cross over in the accumulated costs of Grid and DRE now happens at 5 years.

Scenario 5: Long Time Frame with Solar Panel Replacement Costs

In this scenario, we consider the capital costs of replacing solar panels after 20 years (taking a conservative estimate instead of the standard estimate of 25 years of solar PV lifetime). The CUF is assumed to remain constant at 11%. Here the accumulated cost of DRE comes to INR 10 million over 30 years with solar PV replacement cost of INR 5.3 million in the 21st year. The accumulated cost for the Grid comes to INR 23 million. Hence, even with the solar panel replacement costs DRE proves to be cheaper than the grid in the long run of 30 years.