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International Energy Agency
Photovoltaic Power Systems Programme

Task 18 Off-Grid and Edge-of-Grid Photovoltaic Systems

PVPS

Blueprint on how to conduct feasibility studies on off-grid and edge-of-grid power systems

2022

Report IEA-PVPS T18-01:2022

What is IEA PVPS TCP?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6 000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCP's within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas.

The IEA PVPS participating countries are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America. The European Commission, Solar Power Europe, the Smart Electric Power Alliance (SEPA), the Solar Energy Industries Association and the Cop- per Alliance are also members.

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What is IEA PVPS Task 18?

The objective of Task 18 is to find technical issues and barriers which affect the planning, financing, design, construction and operations and maintenance of off-grid and edge-of-grid systems, especially those which are common across nations, markets and system scale, and offer solutions, tools, guidelines and technical reports for free dissemination for those who might find benefit from them.

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INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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IEA PVPS
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The APVI promotes solar through its live solar mapping platform [http://pv-map.apvi.org.au], the national solar research conference and Australia’s participation in two International Energy Agency (IEA) programs – PVPS (Photovoltaic Power Systems) for solar PV and SHC (Solar Heating and Cooling), concerned with new solar thermal products and services.

List of abbreviations

AC	Alternating Current
BESS	Battery Energy Storage System
BOM	Bureau of Meteorology (Australian Government)
CAPEX	Capital Expenditure
DC	Direct Current
DE	Decentralised energy
DES	Decentralised energy systems
EOL	End of Life
EPC	Engineering, Procurement and Construction
IEA PVPS	International Energy Agency Photovoltaic Power Systems
IRR	Internal Rate of Return
LCOE	Levelised Cost of Electricity
NASA	The National Aeronautics and Space Administration
NPV	Net Present Value
NSRDB	The National Solar Radiation Database
OPEX	Operational Expenditure
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
REPEX	Replacement of Capital Expenditure
SPS	Standalone Power System

Executive Summary

This blueprint provides a step-by-step guideline on how to conduct feasibility studies for off-grid and edge-of-grid power systems. By following the process, one should be able to conduct an effective feasibility assessment for a photovoltaic based off-grid or edge-of-grid power system.

All feasibility studies are different; every project develops in a unique context that consists of different locations, stakeholders, site conditions, aims, constraints, and opportunities. In this blueprint, clear and concise definitions of what a feasibility study is and when and why they should be undertaken in the context of Off-Grid and Edge-of-Grid power systems, provide a solid foundation from which a study can be undertaken.

The blueprint breaks a feasibility study down into the following four stages:

1. Determining the nature and extent of the feasibility study.
2. Gathering information and data.
3. Modelling and analysis.
4. Assessment and recommendations.

Each stage is then split into the following three key project areas that are used to discuss and guide each stage of a feasibility study:

1. Organisational.
2. Financial.
3. Technical.

The purpose of the first stage of a feasibility study is to gain an understanding of the project context and to clearly define the nature and extent of the feasibility study that best suits this context. This involves identifying and engaging with all key project stakeholders to:

- Identify the target audience.
- Identify the project aims and drivers and their relative priority.
- Determine the commitment of and involvement from each stakeholder.
- Assess stakeholder capacity.
- Determine the agreed project assessment criteria.

This second stage focuses on gathering, sorting, and collating the available information and data, which are used in the assessment and modelling work carried out in Stage three. An effective feasibility study requires a considerable amount of information and data to be gathered from a wide range of sources. A key source of information and data will be the project stakeholders, and the gathering process will therefore directly follow on and at times overlap with the stakeholder engagement work of Stage one.

Stage three builds on the first two stages by modelling a range of potential solutions, with the results analysed, summarised, and presented in a meaningful way to help inform decision making. The core outcomes that are required for each element of this stage are:

1. Organisational:
    a. A workable governance structure for the system for its full project lifecycle.
    b. An understanding of the legal and regulatory framework for system deployment and operation.

   c. A general market awareness and understanding of local supply chains for these systems.
2. Technical:
   a. A system design, or range of suitable designs that match the requirements of the project. Underscoring this design will be technical modelling of the power system.
   b. An understanding of the target site(s) and the resultant impacts this may have on the procurement, installation, and long-term operation of the system.
3. Financial:
   a. A model that accurately reflects financial aspects of the project. The detail and complexity of the model should reflect the agreed nature and extent of the feasibility study (i.e., scoping study vs. detailed feasibility) as determined in stage one. Additionally, a key focus is the optimisation of each of these outcomes. As noted previously, the organisational, technical, and financial elements are highly interdependent. Changes to any one of these elements will likely impact other elements. Optimisation therefore will require an iterative feedback process between these three elements to determine the most balanced outcome.

The objective of the fourth and final stage of the blueprint is to bring together all the analysis and understanding of the organisational, technical, and financial aspects of the project, make an assessment as to the whether the project is “feasible”, and provide stakeholders with clear recommendations and guidance on how to proceed. The blueprint provides a general structure for this assessment, some underlying principles to support the assessment, and a range of assessment criteria to be applied against the key project elements.

By following the process outlined in the blueprint, a project manager will be able complete an effective feasibility assessment for a photovoltaic based off-grid or edge-of-grid power system. After conducting a feasibility study of this nature, stakeholders will have a very clear understanding of whether an Off-Grid or Edge-of-Grid PV is feasible, what such a system looks like, the steps required to proceed with a system installation, and how much it is likely to cost.

1 Introduction to feasibility studies

1.1 Scope of this report

The aim of this report is to provide a blueprint on how to complete an effective feasibility assessment for a photovoltaic (PV) based off-grid or edge-of-grid power system. This report examines the key considerations and processes required to successfully determine the feasibility (or otherwise) of such projects and, through the use of case studies, provide the reader with real world examples of such assessments. This report is intended to be used as a general reference guide for persons involved in such projects and hopes to assist the user to successfully navigate some of the common complexities in this area.

1.2 What is a feasibility study?

A feasibility study can be generally described as follows:

> ***"A feasibility study is an analysis of a project that examines all the key aspects of that project to ascertain the likelihood that it can be completed successfully".***

It is a staged process of stakeholder engagement, data gathering, analysis and assessment that allows the project proponent and supporters (i.e. funders) to examine the project in detail prior to any major commitment in terms of time, money and reputation.

While the key aim of a feasibility study is to determine if a project is feasible and therefore should be proceeded with or not, the process of completing a feasibility has many inherent benefits for the project proponent and other stakeholders. Notably a feasibility study provides an opportunity to:

- Better understand the fundamental project goals, aims and desired outcomes
- Uncover the strengths and weaknesses of the project
- Clarify the capacity of key project participants and develop their knowledge and understanding of the project and their role within it
- Identify project risks and measures to mitigate / manage
- Develop effective planning for the deployment of the project
- Identify project constraints and opportunities

1.3 Types of feasibility studies

While all feasibility studies assess factors which have the potential to influence the project's ability to proceed and succeed, the level of detail included within the study itself may vary. Depending on the required detail feasibility studies can be broadly categorised into three main types as detailed below. It is important to note that while it is common for many projects to complete a preliminary assessment or pre-feasibility study prior to commencing a full feasibility study, it is not always necessary to complete multiple types of feasibility studies. The appropriate level of detail, and number of studies required is to be determined by the specifics of the project itself.

1. **Preliminary Assessment**: A scoping study aimed at gathering key information on the project and its context and identifying any red flags that would likely prevent further project development. Preliminary assessments include, but are not limited to:
    - Definition of project goals;
    - Identification of key project stakeholders;
    - Identification of key project risks and red flags;
    - Identification of key factors that may influence project success;
    - Scoping of required works;
    - Identification of additional studies necessary to further assess project feasibility (such as environmental impact assessments, ground resistivity testing, geotechnical studies , etc).
2. **Pre-Feasibility:** A basic project assessment that will consider the key issues and provide a determination as to the feasibility or otherwise of the project. Pre-feasibility studies include, but are not limited to:
    - Definition of project goals;
    - Identification of key project stakeholders;
    - Assessment of key risks and identification of potential management strategies;
    - Detailed assessment of key factors that will influence project success;
    - Development of project scope, including project boundaries and / or constraints;
    - Identification or completion of additional studies to further assess project feasibility (such as environmental impact assessments, ground resistivity testing, geotechnical studies , etc).
3. **Full Feasibility.** A detailed project assessment that will consider the full range of issues and provide a more accurate determination as to the feasibility or otherwise of the project. Full feasibility studies include, but are not limited to:
    - Definition of project goals and indicators of success;
    - Identification of, or early engagement with, key project stakeholders;
    - Assessment of key risks, and development of appropriate management strategies;
    - Detailed assessment of all factors that will influence project success;
    - Finalisation of project scope, including project boundaries and / or constraints;
    - Completion and assessment of additional studies (such as environmental impact assessments, ground resistivity testing, geotechnical studies , etc).

With each increase in detail and complexity in the feasibility, the bankability uncertainty for the project investment subsequently decreases as detailed in Table 1.

Table 1 Level of detail and resultant bankability of feasibility studies

	Preliminary Assessment	Pre-Feasibility	Full Feasibility
Bankability uncertainty	*up to 50%*	*15 - 25%*	*5 - 10%*
Level of detail / effort required	*Up to 20%*	*20 - 50%*	*50 - 90%*
Project design	Indicative design only	Moderately detailed design	Highly detailed design
Stakeholder	Identify	Identify	Identify / engage
Project risks	Identify	Identify	Identify and manage
Technical modelling	No	Maybe	Yes
Financial modelling	No	Maybe	Yes
Site Investigations	Identify	Identify / Complete	Complete
Approvals	No	Identify	Plan
Site Management	No	Identify	Yes
Drawings	No	Key drawings only	Yes
Resource planning	No	Maybe	Maybe

The type of feasibility study required should be determined by the type of project, the potential investment (of time, money or reputation, if the project is to proceed), or the status of the existing knowledge base surrounding the project itself. Understanding and implementing the above will increase the likelihood of the feasibility study suiting stakeholder needs.

Importantly, this blueprint speaks to the requirements of a Full Feasibility study only. As such, should this report be used as a reference when undertaking a Preliminary Assessment or Pre-Feasibility study, inclusion of only a subset of the detail may be necessary. Within all following sections within this blueprint report, the term 'feasibility study' shall refer to Full Feasibility study as defined and detailed above.

1.4 Why conduct a feasibility study?

Access to a reliable supply of electricity is of critical importance to all people and communities. Electricity powers both the delivery of essential services such as water, sewage, communications, security, and health but is also utilised for everyday needs of such as lighting, refrigeration, cooling, heating, cooking and entertainment and in enabling organizations and businesses to run their everyday activities.

Traditionally, off-grid power systems have used either conventional diesel or gas fired generation to meet their electricity needs or were connected to a network that was largely supplied by these same technologies or other thermal based generation (eg coal). Well-managed "conventional" generation systems provide a reliable power source to many locations. However, issues and constraints to reliably accessing and affording such conventional fuels, , along with the challenge of reliably maintaining these systems , led to the consideration of alternative sources of energy as far back as the 1990s.

In recent decades, renewable energy has become an increasingly competitive option for the supply of power in off-grid and edge-of-grid areas, with stand-alone power systems (SPS) consisting of PV and Battery Energy Storage Systems (BESS) installed to either replace or supplement existing diesel systems in off-grid and edge-of-grid locations. Unfortunately, there have been many examples of well-meaning but poorly considered such projects that have partially or wholly failed to deliver on their promise and/or potential. The reasons for these failures are many and varied but, in many cases, can be attributed to mistakes and misunderstandings in the initial feasibility phase of the project, or in some circumstances, an absence of any project feasibility being carried out at all.

The value of deploying PV based off-grid or edge-of-grid power systems in remote and regional areas has been well recognized for more than two decades. As the cost of PV and BESS has declined, the uptake of these systems have rapidly increased. Over this same period there have been many successful off-grid or edge-of-grid power systems projects rolled out in many countries and these systems continue to provide reliable energy services to their communities. Progressing through a feasibility study is one of the first stages required to eventually developing an off-grid and edge-of-grid power system. Moving forward, it is vital that the lessons already learned from installing and operating SPSs are now acting as valuable inputs into feasibility studies.

1.5 Off-grid and edge-of-grid power systems

Off-grid and edge-of-grid power systems are typically designed to meet loads ranging from a few kW’s up to many MW’s. The information provided in this report can be broadly applied to a feasibility study of any scale, however the focus and applicability of this report is on power systems sized anywhere between 10 kW – 10 MW.

IEA PVPS Task 18 defines off-grid and edge-of-grid power systems below [1].

1.5.1 Off-grid

Off-grid refers to electrical systems or grids which are remote from the main electrical grid which are most often state owned or regulated electrical systems. This is not to say that an off-grid system cannot be state owned or regulated, but that an off-grid system stands alone from the principal infrastructure of a, typically, state owned or regulated grid. Examples of an off-grid system include:

- A single dwelling powered by a generation system
- An islanded mini-grid, powered by either thermal or renewable generation
- A power system which provides electricity to an entire island community consisting of hundreds of people (communities not connected to the main grid)
- A communications node located in a remote area

- A temporary work site such a remote mine

1.5.2 Edge-of-grid

Edge-of-grid refers to areas where the main electrical grid may be unstable or not fit for purpose and the use of systems which include PV may serve as a solution. Edge-of-grid areas are often exposed to similar issues as off-grid areas with regards to reliability, resiliency and security and PV may provide part of the solution for these areas. Examples of edge-of-grid systems include:

- Grid connected communities which are located hundreds of kilometres away from principal electrical infrastructure
- A single, grid connected asset which is located in an area which is expensive for a utility company to service
- A grid connected microgrid where the grid connection provides poor power quality and/or poor reliability

2 The feasibility blueprint

The term "feasibility study" is subject to a broad degree of interpretation. It covers a wide range of possible approaches that will likely vary with the circumstances of the project. For the outcomes of a feasibility study to be sufficiently reliable there are fundamental areas that need to be addressed. The following Blueprint provides an overview of what is required to complete a successful feasibility study. The key areas that need to be considered to achieve this end goal are discussed. It offers a staged approach to carry out a feasibility study, that includes organisation, technology, and finance.

A summary of the general structure of this Blueprint is below:

- **Project staging:** The feasibility study process requires the effective completion of the following four distinct stages:
    1. Determine the nature and extent of the feasibility study
    2. Gather information and data
    3. Modelling and analysis
    4. Assessment and recommendation

  As a general principle the completion of each stage allows progression to the next, thus each of the stages are typically completed consecutively. However, the staging is primarily to provide structure to the process and the relationship between stages is not likely to be directly linear as there is likely to be considerable iteration and overlapping between stages.

- **Key elements:** There are three broad elements upon which the feasibility of the project should be assessed, which include:
    1. **Organizational**: governance, ownership, management structures, land tenure, legal/regulatory frameworks, stakeholder understanding and acceptance, procurement, market analysis , etc.
    2. **Technical:** Hardware, equipment, site assessments, buildability, and system modelling

3. **Financial:** Life cycle project costings, financial assessment, and modelling

These three elements also form a useful division of works for each stage of the feasibility study. It is important to note though that these three elements are highly interdependent and therefore there is considerable crossover between these elements in terms of their impact on the feasibility study.

- **Other General Considerations:** While every feasibility study is different and dependent on the context in which it is applied, some of the considerations that are consistent across most scenarios include:
  1. **The feasibility assessment should consider the full life cycle:** Off-grid and edge-of-grid power systems utilising PV technology are generally designed to operate for the design life of the main generation component – the solar panels, which is in the order of 20 – 25 years. They typically require significant upfront capital expenditure (CAPEX) and relatively low operational expenditure (OPEX). To provide meaningful and cost-effective outcomes a feasibility study should assess the full life cycle period.
  2. **The importance of accurate information:** Accurate information is important in establishing quality outcomes. Gathering such information can be difficult for many projects but where possible should be a key early priority as the return value on such effort is generally high. If the accuracy of input data is in doubt, reasonable allowances in the feasibility study assessment should be made and be clearly documented.
  3. **Off-grid and edge-of-grid:** These two scenarios are very similar from the standpoint of a feasibility study. There are technical and financial metrics unique to each scenario, but the overall process is the same and many of the results and findings are highly interchangeable.

Figure 1 provides a high-level summary of the structure of the Blueprint and provides a more visual description of the relationship between the four key stages and the three key elements.

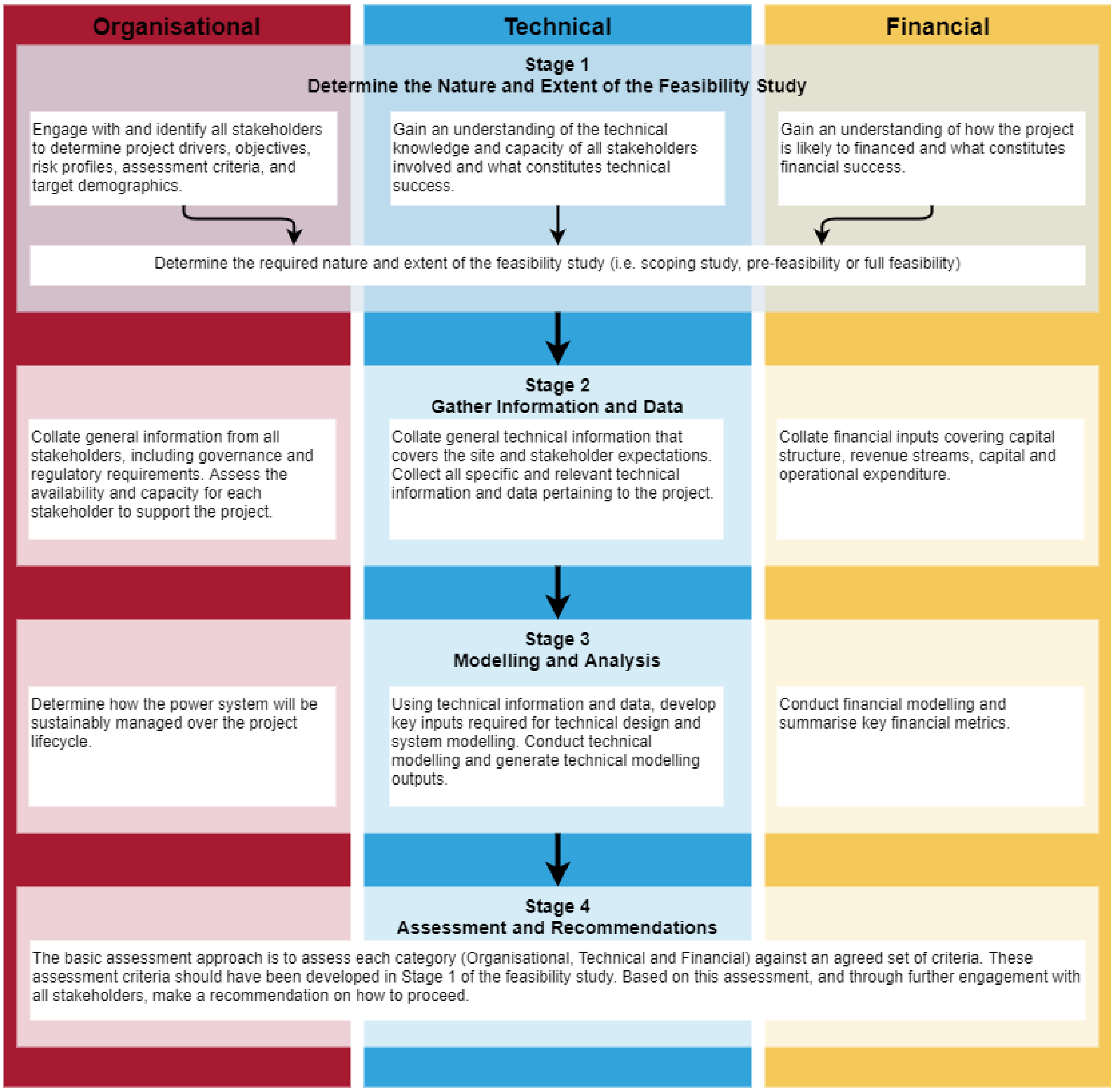

Figure 1. High-level framework for conducting a feasibility study on off-grid and edge-of-grid power systems

2.1 Stage 1: Determine the nature & extent of the feasibility study

2.1.1 Stage 1: Overview

As has been noted, all feasibility studies are different; every project is applied in a unique context that consists of different locations, stakeholders, site conditions, aims, constraints and opportunities. The basic purpose of this first stage is to gain an understanding of the project context and then clearly define the nature and extent of the feasibility study that best suits this context.

Stage 1 involves identifying and engaging with all key project stakeholders to:

- **Identify the target audience:**
  - Who wants and/or needs the feasibility study to be completed (e.g. funders, financiers, Government, non-Government organisations , etc.) and why?
- **Identify the project aims and drivers and their relative priority eg:**
  - Improved provision of energy services (e.g. reliability, availability, security, quality of supply).
  - Financial benefit (e.g. reduced operating cost, higher company profit, hedging against fuel price uncertainty , etc.).
  - Better environmental outcomes (e.g. reduction in fuel based greenhouse gas (GHG) emissions, improved air quality, reduced noise, reduced risk and/of fuel/oil spillage , etc.).
  - Developing other opportunities and livelihoods that require reliable energy services.

- **Determine the commitment of and involvement from each stakeholder**:
  - What is driving their involvement?
  - Are there limitations of this involvement and if so, what are they?
  - What is the acceptable risk profile?
- **Assess stakeholder capacity:**
  - What is the organizational, technical, and financial capacity of each stakeholder?
  - What areas may require support and/or development?

- **Determine the agreed project assessment criteria:**
  - What are the metrics by which outcomes of the feasibility study will be evaluated?
  - Does each stakeholder understand and agree on the assessment criteria? [*these assessment criteria will help guide the Assessment and Recommendations stage and reduce the likelihood of disagreement between stakeholders as to the direction the project takes. Refer to Stage 4 of this blueprint for typical examples of assessment criteria.*]
- **Understanding the project:**
  - Ensure all project participants have a sufficient level of understanding of the project to allow for effective involvement and contribution and to ensure informed consent for any project commitments.
  - Address any identified misunderstandings before progressing further.

2.1.1.1 Project stakeholders

The possible project stakeholders and their roles in off-grid and/or edge-of-grid projects is diverse and highly dependent on the type and location of the project. Typical stakeholder groups include:

- **Project proponents** are typically the driving entity behind the project and can come from a wide range of groups including government or non-government organizations (NGOs), investors, utilities or end users such as commercial entities or community groups. The project proponent commonly initiates the feasibility study as a first project step or is required to do so by project funders and financiers.

- **End users and site owners** covers those who live or own the facilities that the proposed power system will service:
    - Community: ranges from single households or clusters of households to whole towns
    - Commercial: highly variable, but commonly includes tourism, mining & agricultural facilities
    - Government: highly variable, but includes military, monitoring, scientific facilities such as ranger stations, meteorological stations , etc.

  Including end users in the feasibility study is an important aspect as they are the final recipient of the energy service. This involvement may be passive, but for community focused projects this involvement may extend to that of funding, ownership and management of the system.
- **Government** includes national, regional & local governments. Typical roles for government in these projects include facilitators, funders, system owners or managers, and provision of legal and regulatory oversight.
- **Project funders and financiers** include governments and NGO's, financial institutions, investor groups, commercial interests, end users and site owners. Funding is typically for CAPEX but may also include supporting OPEX. Financial support for the project may be provided in many forms including grants, loans, asset leasing, stakes in project equity , etc.
- **Utility and network owners** are energy service providers where energy services (or an obligation to provide energy services) already exist. These service providers generally include government or private utility companies and network owners. Their interest or involvement may range from being the project proponent and/or project funders to simply be consulted about changes to their existing assets or responsibilities.

2.1.1.2 Stakeholder engagement

Stakeholder engagement is a critical component of a feasibility study and is the core activity in first stage of this blueprint. The nature of this engagement will vary greatly, depending on the stakeholder and their role in the project. For example, the engagement with institutions from whom project funding is being sourced will be very different from the engagement with a remote community for whom the proposed power system is being located. However, the basic goals of engagement as described in Section 2.1.1 are the same for all stakeholders.

The following list is a guide to some of the questions that need answering through the process of gathering information from stakeholders:

- Do they understand the project and its possible implications (organizationally, technically and financially) once deployed?
- What are they wanting to achieve by being involved in the project?
- What are their project expectations (and are these expectations realistic)?
- What are the metrics by which they would measure project success (or otherwise)?
- What is the nature of their role, particularly in regards to decision-making, within the project?
- What is the nature of their project commitment/involvement (time, funding, knowledge, governance, ownership , etc.)?

- Do they have the capacity to deliver on their commitment? If not, can this capacity be built within the project framework?

A crucial activity of this first stage is to work through these differences where they exist to ensure that there is basic agreement on key project fundamentals. These fundamentals include but are not limited to funding and tariff arrangements, system ownership, governance and management.

2.1.2 Stage 1: Organisational

The term "organisational" covers all non-technical and non-financial considerations and largely dictates the development, structure and deployment of the project and includes the following areas:

1. System governance, ownership & management structures
2. Legal & regulatory frameworks
3. Market analysis, supply chains and procurement

2.1.2.1 Governance, ownership & management structures

It is reasonable to assume that a well-managed PV off-grid or edge-of-grid power system will function for 20-25 years, and beyond. For this duration in operation to be achieved, robust and functional governance structures are required to be put in place over this full system life cycle. The fundamental purpose of these structures is the formal and legal allocation of responsibility for system ownership and the management of technical and financial aspects of the proposed project.

During this first stage, the focus of the engagement is to explore governance options for the project to gain an understanding of the perspective of each of the various project participants. It is important to ensure all project stakeholders understand and accept that effective long term project governance is an essential requirement for the project to proceed and succeed. It also provides an opportunity to explore their interest and capacity in taking on possible roles and responsibilities in the project ownership and management and for them to understand financial and resourcing implications that would result from their involvement.

2.1.2.2 Legal & regulatory frameworks

It is important to identify and understand the legal and regulatory frameworks within which the project will be functioning. This will help define the nature and extent of the feasibility study within the context of the given project, key constraints and processes required to progress. Some of these considerations will include but not be limited to:

1. Contractual arrangements for system procurement, operation and ownership
2. Regulatory compliance
    - Power system and networks
    - Tariffs and energy service quality requirements
    - Environmental regulations
3. Installation standards and quality assurance

2.1.2.3 Market analysis, supply chains and procurement

The successful deployment and operation of off-grid and edge-of-grid power systems requires an understanding of the market environment, supply chains and a well thought out procurement process. Much of the required assessment for this area work will be carried out in Stage 2 (Information and Data Gathering) of the blueprint, however a general awareness of the market and its strength and limitations in delivery of services related to off-grid and edge-of-grid power systems is important in framing the extent and nature of the feasibility study. Areas of note include:

- Understanding of local versus regional supply chain capacities
- Capacity of existing supply chains to deliver the required services
    - Technical/financial capacity
    - The need for capacity building
- Time/cost implications of weak supply chains
- Possible incentives for supply chain development and support
- Impact of supply chains of site selection (remote or difficult access)

2.1.3 Stage 1: Technical

The term "technical" encompasses any information relating to the technical viability of the project, which includes the project's physical aspects, delivery, and operation. Often this includes information related to the site itself, the engineering, design, hardware, structures, functionality, operation, and maintenance.

In Stage 1 of the blueprint, the goal of engaging with stakeholders in the context of technical information, is to gain an understanding of:

4. The technical knowledge/capacity of the project proponent and other stakeholders
5. Any technological preferences or requirements for the project
6. Any major site limitations/constraints that will impact the feasibility process (e.g. limited site access , etc.) or direct the technical response (eg structural design for cyclonic areas)
7. Metrics or parameters by which the project proponent(s) will gauge the technical success of the project

2.1.4 Stage 1: Financial

The term "financial" encompasses any information related to determining the project's financial viability, which includes capital structure (e.g. funding, debt and equity terms, tax , etc.), costs (i.e. capital expenditure, operational expenditure and replacement costs for critical infrastructure), and value streams (e.g. electricity sold, green certificates, reduced fossil consumption, reduced maintenance costs).

In Stage 1 of the blueprint, the goal of engaging with stakeholders in the context of financial information, is to gain an understanding of:

8. Any particular financial preferences or requirements for the project
    - E.g. community investment, community owned , etc.
9. Any financial limitations/constraints that will impact the feasibility process
    - E.g. budget and/or lending constraints, expectations on returns , etc.
10. The metrics by which the project proponent(s) will gauge the financial success of the project
    - E.g. profit, rate of return, payback period, operational cost, minimal upfront investment , etc.

11. How the project is likely to be financed?
    - E.g. proportion of debt/equity finance, grant funding, government incentives , etc.
12. What the likely terms and conditions of all funding sources will be?
    - E.g. cost of debt/equity, tenure, refinancing, debt service coverage ratio , etc.
13. What tax rate will the project be subject to?
    - E.g. some clients (e.g. some religious entities) and/or projects may not be subject to pay tax

2.1.5 Engagement Example: Village electrification

A common example of off-grid power system development is village electrification, which in many cases involves the deployment of a power system and distribution network in a community that has previously had little or no access to electricity. In this scenario the community itself is the end user and a key stakeholder. The community engagement in this first stage will be tailored to the specific project needs and a fundamental outcome should always be the delivery of information to the community, gaining an understanding of their desired project aims and outcomes and ensuring informed consent for their involvement. Common areas that need discussing (Figure 2) with the community include:

- A general explanation of the proposed project so it can be understood by the community in terms of benefits and limitations. It is important to be able to carefully manage unrealistic expectations from stakeholders on what the proposed power system may be able to deliver within the available funding and capacity constraints.
- A basic technical explanation of the proposed system, operational lifespan and how it will operate day-to-day, including limitations (eg as opposed to supply from a main grid)
- Identify what responsibilities and involvement the community may need with the system development, construction, and ongoing operation and maintenance.
- Assess community capacities and identify what additional support structures or training may be required to allow the community to effectively fill their agreed roles.
- Identification and explanation of the financial aspects of the system (tariffs, OPEX and Replacement Expenditure (REPEX) costs) and how these will impact the community and can be most effectively managed.
- Requirements for formal sign-off around key commitments and agreement

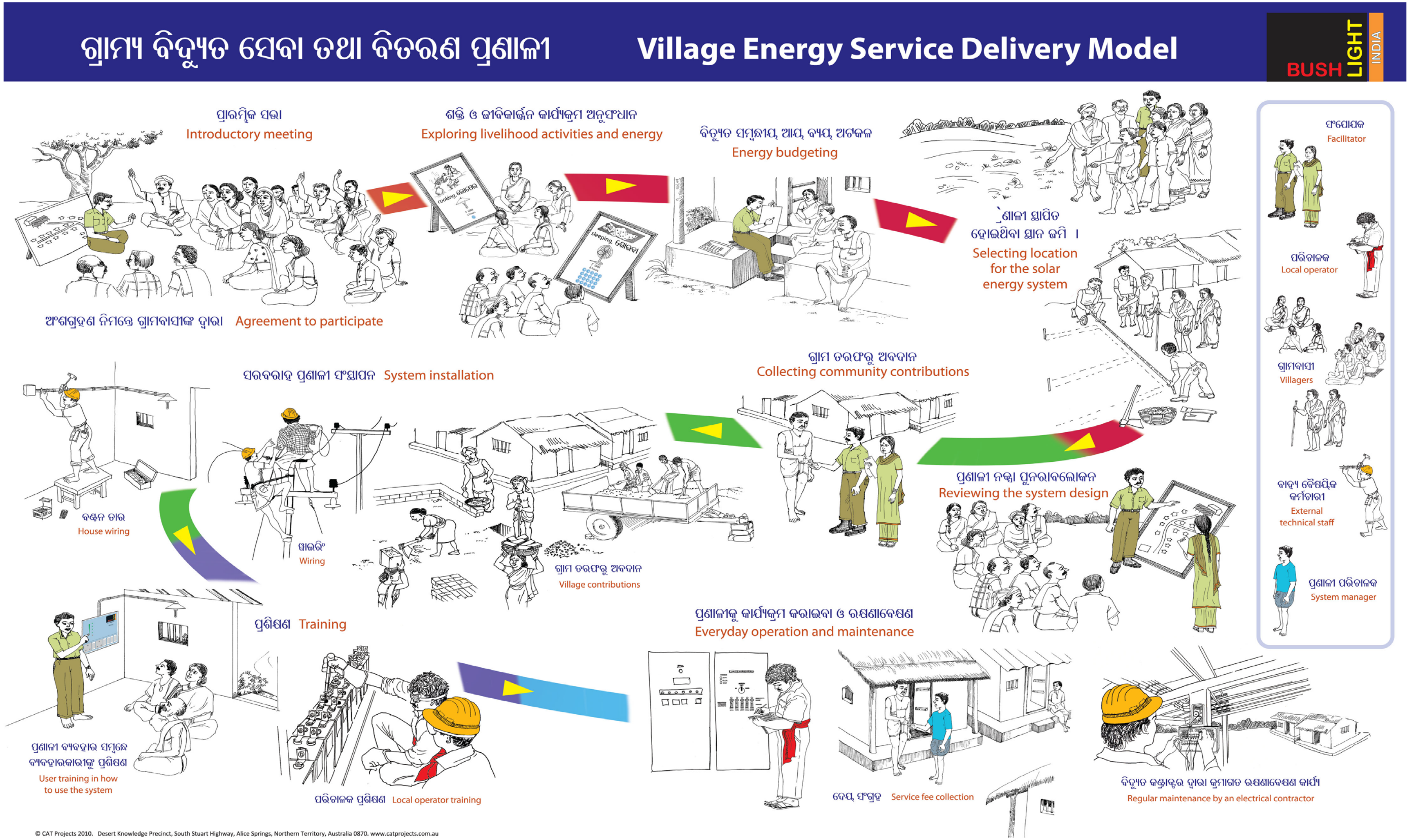

Figure 2: Example of community engagement resource (in local language) showing the full project process

2.2 Stage 2: Information and Data Gathering

2.2.1 Stage 2: General

This second stage of blueprint focuses on gathering, sorting and collating the available information and data on all aspects of the project. This information and data will form the basis of the assessment and modelling work carried out in Stage 3. An effective feasibility study requires a considerable amount of information and data to be gathered from a wide range of sources. A key source of information and data will be the project stakeholders themselves and the gathering process will therefore directly follow on and at times overlap with stakeholder engagement work in Stage 1.

The following sections look at the specific information and data that will need to be gathered on the organizational, technical and financial aspects of the project and where they can be sourced.

2.2.2 Stage 2: Organisational

As noted in Section 2.1.2 the organisational element of the blueprint focuses on understanding and assessing the following key areas.

1. System governance, ownership & management structures
2. Legal & regulatory frameworks
3. Market analysis, supply chains and procurement
4. Land access and tenure

The nature of the required information and the means of gathering of information and data for these three areas requires three different approaches. These approaches are summarized below.

2.2.2.1 Governance, ownership & management structures

The project requires that an agreed upon and workable structure be set up for the governance, ownership and maintenance of the proposed power system. Depending on the project scenario and the key stakeholders, there are many possible options or approaches that could be successfully deployed. These include but are by no means limited to:

- **Owner operated:** The end user owns, operates, and manages the power system. The end use may be an individual, a whole community or a commercial entity.
- **Conventional utility model:** The plant is owned and managed by an established power utility and the end user's role is simply as a paying consumer.
- **Private sector model:** Similar to the conventional utility model except the plant is owned and managed by an Independent Power Producer (IIP), usually registered and subject to some form of regulation
- **Hybrid model:** Where some combination of the key stakeholders (i.e. end users, utility and/or IIP) collaborate in terms of ownership, operation and management of the system.

Determining the optimal approach for the project requires a continuation of the Stage 1 engagement with the project stakeholders but with a specific aim of determining what the governance structure for the project will be. The gathering of information will be focused on stakeholders to determine their:

- **Goals:** do their project goals align with the project as a whole?
- **Commitment:** what project roles and responsibilities are they willing to take on?
- **Understanding:** do they understand the project and what their proposed commitment will require?
- **Capacity/capability:** do they have the capacity (e.g. time, funding, knowledge, governance) to fulfil their proposed commitment and if not, can this capacity be built within the project time frame?

Determining a workable and long-lasting governance structure for the project is a critical but often overlooked aspect. Engaging effectively with key stakeholders and gathering of the aforementioned information is therefore critical to the sustained success of the project.

2.2.2.2 Legal & regulatory frameworks

The information and data required for legal & regulatory frameworks will be gathered from a range of sources including project stakeholders, government and regulatory authorities, utility and network operators and others. Areas where information and data on available options and requirements may include:

14. **Contractual considerations**
    - Engineering Procurement and Construction (EPC)
    - Operations and Maintenance (O&M)
    - Offtake agreements
    - Loan/financing agreements
    - Ownership agreements
15. **Regulatory compliance**
    - Development approvals
    - Zoning and land access
    - Impact Assessments
        - Environmental
        - Gender equity
        - Social
    - Certifications (e.g. structures, electrical , etc.)
    - Technical approvals and requirements
        - Network connection (edge-of-grid)
        - System design requirements (utilities or others)
    - Tariffs and energy service quality requirements
        - Tariff structures, metering and billing requirements
        - Power quality requirements
16. **Standards and quality assurance**
    - Local and/or international installation and quality standards
    - Required quality systems for project participants
    - Work health and safety standards

2.2.2.3 Market analysis, supply chains and procurement

As noted previously, a general awareness of the local market and its strength and limitations in delivery of services related to off-grid and/or edge-of-grid power systems is an important part of the feasibility study. To this end, gathering information and data on the following areas will allow for a general market assessment in Stage 3 of the blueprint:

- Capacity of local supply chains in terms of the availability and delivery of:
  - EPC services
  - O&M services
  - Suitable hardware and equipment (e.g. reliable, portable, serviceable)
  - Manage logistics and delivery to difficult and/or remote locations
- The scope for building additional capacity where gaps are identified
- Possible incentives for supply chain development and support
- Time/cost implications of weak supply chains
- Impact of supply chains of site selection (e.g. remote or difficult access)
- Willingness of project stakeholders to engage with existing supply chains

2.2.2.4 Land access and tenure

An important additional consideration for the successful deployment of any off-grid and/or edge-of-grid system is long term access to suitable land that hosts the power system and its associated network. It is highly dependent on the local context, but land access is often a major issue for projects. Some considerations include:

- **Availability:** An off-grid power system that relies heavily on PV generation typically occupies 1.2 - 1.6 m^2 per kW of PV. Consideration should also be given for the need to ensure sufficient space for any future expansion of the system.
- **Condition:** The site must be suitable to house the power system over its whole project life. The site risks should therefore be well understood so that they can be avoided or managed and include:
  - difficult ground conditions: sandy, swampy (e.g. acid soils), rocky , etc.
  - inundation or flooding
  - sea level rise
  - rapid revegetation, regrowth, bush fire
  - human interaction (e.g. theft and vandalism)
  - environmental exposure (e.g. sea air, dust, heat , etc.)

  Geotechnical assessment and formal site surveying are useful early assessment measures that should form part of a detailed feasibility study.
- **Existing tenure:** Secure tenure for the power system land for its full life cycle is a fundamental project requirement. It requires the temporary (e.g. lease, loan , etc.) or permanent (e.g. gift or sale) transfer of land to the project. Existing land can be owned by individuals, governments, communities, NGO's, religious organisations and/or commercial entities.
- **Cost:** The cost associated with gaining land tenure will vary greatly depending on the context. It may be freely given or loaned, it may be leased, or it may be sold. Invariably however there will be a cost for land use which will need to be factored into the overall feasibility.

Negotiating land access and tenure can be one of the more difficult issues for a project which can involve significant time and effort to resolve. Land use and ownership are often contested areas in communities and whilst it is highly dependent on the project scenario there is notable potential for disagreement and disharmony between stakeholders on this issue and therefore requires careful consideration.

2.2.3 Stage 2: Technical

Gathering technical information is a core requirement for the development of the proposed system design. The common sources of technical information include:

- Engagement with key stakeholders (e.g. remotely or face to face)
- Site assessment: typically requires one or more visits to the project site
- Documentation supplied by stakeholders or other parties, some of which include:
    - Drawings and maps (e.g. layouts, schematics, service drawings, topographical , etc.)
    - Documents and historical records (e.g. past reports, fuel bills, meter data, O&M records, community demographics , etc.)
- Government or private research agencies (e.g. meteorological data, census data , etc.)

The information and data that should be gathered includes:

- Key technical information and data:
    - Stakeholder expectations on the new power system
        - What loads it will meet
        - Required renewable energy fraction (REF)
        - System availability (e.g. 24 hour per day, 365 days per year)
        - System reliability (e.g. acceptable frequency and duration of outages)
        - Expected impacts on existing operations (e.g. diesel savings, reduced maintenance , etc.)
    - Current and expected future electrical loads:
        - Site metering and load surveys
        - Past electrical and/or fuel bills
        - Proxy load data from similar sites
    - Growth projections (e.g. population, usage, load , etc.)
    - Drawings, schematics and layouts:
        - Single line diagrams, network layouts and site surveys
    - Summary of existing site assets including:
        - Generation system, network, distribution and metering
        - Buildings and other structures
        - Services: water, sewage, telecommunications and how they interface with the power system
    - Hardware specifications for existing equipment
    - O&M records of existing plant
    - Renewable resource data (e.g. irradiance, wind , etc.)
    - Geotechnical assessment and site surveys of the proposed work area
    - Options for energy efficiency measures to reduce load or change load profiles

- General Site Information:
  - Site location (i.e. geographical position)
  - Site maps and layouts
  - Site accessibility (seasonal/annual, stating which vehicle types/loadin permissible)
  - Site facilities for contractors (e.g. accommodation, potable water, ablutions , etc.)
  - Selection of preferred sites for new system equipment

2.2.4 Stage 2: Financial

In preparation for Stage 3 of the blueprint: modelling and analysis, the following financial information must be gathered to develop the necessary inputs to conduct financial modelling.

2.2.4.1 Capital structure inputs

The capital structure of a project will impact its feasibility and often cannot be established until the revenue model is understood. Investment can come from different sources and at many different stages of the project, with all investments exposed to different levels of risk and demanding varying levels of return. Some potential sources of funding and investment include, but are not limited to, examples in Table 2.

Table 2. Possible sources of investment

Source of investment	Description
Debt	Raising debt can be done through many different financial institutions or impact/social investors not looking to have ownership of the project but financially support its development. Debt can be provided from multiple different sources and at different tiers, where certain tiers of debt are paid out in different orders and at different rates.
Financial institutions	Financial institutions include banks, Government-owned green banks, national development banks , etc.
Impact/social investors	Debt may also be sourced from impact/social investors looking to receive a return on investment while supporting the development of a project working towards an idea that the investor believes in.
Equity	Raising equity can be conducted in two stages. First, raising seed capital from risk tolerant investors, then looking to approach community residents once the project is further into the development phase and the risk profile is better understood. If community residents are not willing to expose their investment to early project development risk, it is optimal to cover the project costs for as long as possible from grant funding, angel investors, impact investors and/or commercial developers.
Community residents	There may exist a range of investor types in the community, with some more suited to early-stage development funding than others. Community residents are often the most patient investors and can be willing to accept little to no return on their investment if it means seeing

	the project come to life and benefit the local community in either social and/or environmental ways.
Local entrepreneurs	It can be a good idea to look to local entrepreneurs who have experience in building local enterprises, who are well connected and know how to manage risk. These local entrepreneurs may be willing to not only provide initial investment to the project but may also provide professional advice on the project's operations.
Angel investor	An angel investor is someone with access to significant capital that has experience investing in start-ups where they are often exposed to large amounts of risk. These investors usually look to exit the investment, with relatively large returns, once the venture is up and running. These investors can provide additional help to the project by playing an advisory role, however, they rarely invest long term.
Impact/social investor	Impact, or social investors have access to significant capital and are similar to angel investors but differ by looking for more of a social return on their investment and are seen somewhat as philanthropists.
Energy project developers	Through early engagement with developers, one may be willing to solely fund and conduct all or part of the early-stage development phase, as it can be difficult for small community projects to secure high-risk capital. A developer that is willing to cover all or part of the development phase will most likely demand compensation for the extra risk exposure. This compensation can be delivered in several ways. Some developers may decide they want more control over the project, a larger portion of equity relevant to their investment, a higher risk premium, additional marketing, or, the developer may be looking to improve their corporate social responsibility by being seen to support and work with communities. While ensuring the risk and return is appropriate for the level of investment provided by the developer, it is important to simultaneously gauge each developer's capability to deliver on the project.
Funding/grants	Funding and grants are often provided to support the development of a project in cases where it would not likely succeed without financial support.
Local, State and Federal Government	As off-grid and edge-of-grid projects often bring much more than just renewable energy benefits to the region, it's important to pursue all possibilities of securing grant funding by applying for government grants in the areas of renewable energy, education, capacity-building, regional resilience and employment.

The common inputs required to determine the capital structure of the project are provided in Table 3.

Table 3. Common financial structure inputs to the financial model

Financial model input: capital structure	Description	Example Value(s)
Debt amount	The amount of money being sourced from debt providers. Debt is required to be paid back via annual interest and principal repayments, although the terms and conditions of debt financing change depending on the risk context of the project	60-90% of total cost

	and borrower. Debt is usually a cheaper source of finance, when compared to equity.	
Equity amount	The amount of money being sourced from equity providers (e.g. shareholders, community members, individuals). Equity contributions signal ownership of the project. Often debt providers will require a certain proportion of equity investment so that owners are incentivised for the project to succeed.	10-40% of total cost
Funding, grants, and incentives	This is any amount of money sourced to support funding the project that is not required to be paid back. Renewable energy projects often attract Government incentives, grants or funding and ultimately reduce the required contributions from debt and equity providers.	NA
Cost of debt	The cost of debt is the annual cost of borrowing money from debt providers. It represents the annual repayment required as a percentage of the outstanding debt owing (i.e. interest repayment). Annually, interest repayments on debt are calculated by multiplying the cost of debt (i.e. interest rate) by the outstanding debt owing.	3-5%
Cost of equity	The cost of equity is the amount that equity holders expect in return for providing equity funding. Returns on equity are paid out from profits, after the majority owners, or boards, have decided what amount to retain for reinvestment or emergencies. For these reasons, equity investments are considered riskier than debt and demand relatively higher returns.	6-14%
Weighted Average Cost of Capital (WACC)	The WACC is the weighted average cost of capital and is the rate at which future cash flows are discounted to get values in present terms.	3-8%
Tax rate	The rate at which profits are required to pay tax.	0-40%
Inflation	The rate of inflation.	1-4%

2.2.4.2 Value proposition inputs to the financial model

Some of the common value propositions for off-grid and edge-of-grid hybrid power stations are provided in Table 4.

Table 4. Common value propositions

Financial model input: value proposition	Description
Selling generated electricity	Value propositions for off-grid, edge-of-grid and edge-of-grid power stations might include the selling of generated electricity. This electricity can be sold through different mechanisms depending on the context in which the project is applied. Depending on the size of a grid-connected power system, it may be able to sell electricity on the spot market – however this situation is unlikely in the context of off-grid and edge-of-grid. Electricity may also be sold under a tariff arrangement, where electricity is sold to customers based on connection fees, time of consumption, total consumption, and peak consumption. Offtake agreements may provide long-term certainty on the sale of electricity at pre-arranged prices. The terms and conditions of offtake agreements vary and depend on the parties involved. Securing offtake agreements early in the development stages of a project can be vital to determining and securing the capital structure for the project. For example, investors prefer to provide funding if the revenue models are known as there is less risk once the project enters the operational stage.
Reducing diesel/gas fuel consumption and generator maintenance	The installation of renewable energy in off-grid and edge-of-grid power stations results in operating diesel and/or gas generators less often. This reduces the diesel and/or gas fuel consumption, saving on OPEX over the project's lifecycle. Reducing the operations of diesel and/or gas generators also saves costs on maintenance of these assets. The reduction in OPEX from installing renewable energy is a key value proposition for off-grid and edge-of-grid hybrid power stations. Technical model outputs need to quantify this reduction in OPEX and be provided as an input to the financial model so the benefits can be captured.
Receiving benefits from green schemes	Many different green schemes apply for renewable energy projects around the world and depend on the context in which the project is applied. It's important to quantify and capture the financial benefits from green schemes in the financial model.

2.2.4.3 Cost inputs to the financial model

Some of the common cost inputs for off-grid and edge-of-grid hybrid power stations are provided in Table 5.

Table 5. Common cost inputs to the financial model

Financial model input: costings	Description
Initial expenses	These expenses might include, but are not limited to, project management, engineering, and development fees. It may be worthwhile applying a contingency fee also to account for a worst-case-scenario when exact costs are not certain. The contingency amount will change depending on the level of uncertainty in cost predictions. If initial expenses are not known, it may be reasonable to estimate these based on a percentage of total capital expenditure.
Capital expenditure (CAPEX)	CAPEX includes all costs involved with procuring physical assets, building the project, and reaching commissioning. CAPEX might include, but is not limited to, the cost to procure and build the following key infrastructure: - Solar PV - Wind turbines - Hydro infrastructure - Transformers - Inverters - Batteries - Diesel and/or gas generators (new or upgrades to existing) - Network (new or upgrades to existing) - Balance of plant - Labour
Replacement of critical infrastructure (REPEX)	REPEX is not always considered its own category of cost and sometimes falls either under CAPEX or OPEX. To be explicit for readers of this Blueprint, REPEX here is considered as its own category of cost. REPEX includes any cost associated with the expected replacement of critical infrastructure that are expected to fail before the project's lifecycle is reached. Critical infrastructure includes equipment that are vital in the assets continued operation. REPEX might include, but is not limited to, the cost of replacing items such as: - Inverters (typical lifespan of 10-15 years) - Batteries (typical lifespan of 8-20 years) - Diesel/gas generators (dependent on operation) - Network infrastructure (dependent on age of infrastructure)
Operational expenditure (OPEX)	OPEX includes all costs associated with operating the asset over the project's lifecycle. OPEX items typically fall under either a variable or fixed category. The variable OPEX items change depending on how each asset is being operated and include, but are not limited to: - Diesel/gas generator maintenance - Diesel/gas generator overhaul -

Financial model input: costings	Description
	The fixed OPEX items are unrelated to how the asset is being operated and include, but are not limited to: - Solar maintenance - Battery maintenance - Network infrastructure maintenance - Insurance - Leasing of land - Asset management Vegetation management

2.2.4.4 Forecasting inputs to the financial model

Most off-grid and edge-of-grid renewable energy hybrid power systems have expected lifetimes that span anywhere from 20 – 30 years. Forecasts are required to be developed and applied to variables where changes in values over that time are likely. A list of common variables that require forecasts being developed and applied in financial models are provided in Table 6.

Table 6. Common forecasts required in the financial model

Financial model input: forecasts	Description
Electricity price, tariff, offtake agreement , etc.	Changes in annual revenue need to be accounted for over a project's lifecycle. Changes to the price points in the way a project generates revenue, whether that be through trading electricity on the spot market, receiving payments through an offtake agreement, or having customers pay for electricity according to tariff structures, are required to be forecast.
Diesel/gas fuel price	Paying for diesel and/or gas is often one of the largest ongoing costs for operating power stations. The value proposition for installing renewables in off-grid and edge-of-grid locations usually revolves around offsetting future consumption of fossil fuels. Not only is the cost of fossil fuel a large proportion of the total OPEX, is it also often the most unpredictable. Stakeholders can be willing to invest significant upfront capital only to ensure more certainty on future cash flows by reducing the exposure to fossil fuel consumption. The price of diesel and/or gas is extremely volatile and difficult to accurately predict over extended periods. Forecasting the diesel and/or gras price is a critical aspect of a financial model and can introduce the most risk in a feasibility study.

Green schemes	Government policy will change over a project's lifecycle. Political landscape is often extremely volatile and too risky to attempt to predict. While it's possible that new green schemes may be introduced over a project's lifecycle, it's not recommended to forecast revenue streams from non-existent green schemes. Revenue from green schemes that are dependent on generation or market pricing are required to be forecast for the duration of the policy to minimise uncertainty associated with this revenue stream. For example, Australia has a small-scale and large-scale renewable energy certificate scheme. Revenue received through these schemes depend on the quantity of energy generated, and the timing at which the green certificates are traded. Therefore, forecasting the small-scale and large-scale certificate prices are an important aspect in financial models.
REPEX items	The cost for any key infrastructure that is likely required to be replaced before the project's lifecycle is reached requires a price forecast to be developed and applied in the financial model. A list of the likely REPEX items that require price forecasts to be developed are provided in Table 5. Cost forecasts are required to be thoroughly researched and often introduce significant uncertainty to the modelling. A common example is accounting for the cost to replace a battery in year 10 of the project's lifecycle. The estimated cost of procuring and installing a battery in 10 years' time is required to accurately account for this cost.
Inflation	Forecasting inflation is important as the price of many variables in a financial model are assumed to follow inflation. For example, the price of labour is often assumed to increase with inflation over time.
Exchange rate	Any project planning to pay for infrastructure or expertise over the project's lifecycle in a different currency is subject to exchange rate risk and requires a forecast for the relevant exchange rate to be developed and applied.

2.3 Stage 3: Modelling and Analysis

2.3.1 Stage 3: General

The goal of Stage 3: modelling and analysis, builds on from the first two stages by testing a range of potential solutions through modelling, where results are analysed, summarised, and presented in a meaningful way to achieve a desired outcome. The core outcomes that are required for each element for this stage are as follows:

1. **Organisational**
    - A workable governance structure for the system for its full project lifecycle.
    - An understanding of the legal and regulatory framework for system deployment and operation.
    - A general market awareness and an understanding of local supply chains for these systems.
2. **Technical**
    - A system design, or range of suitable designs, that match the requirements of the project. Underscoring this design will be technical modelling of the power system.
    - An understanding of the target site(s) and the resultant impacts this may have for the procurement, installation, and long-term operation of the system.
3. **Financial**
    - A model that accurately reflects financial aspects of the project.

The detail and complexity of these core outcomes should reflect the agreed nature and extent of the feasibility study (i.e., scoping study vs. detailed feasibility) as determined in the first stage of this blueprint process. Additionally, a key focus of Stage 3 is the optimisation of each of these outcomes. As noted previously, the organisational, technical and financial elements are highly interdependent. Changes to any one of these elements will likely impact other elements. Optimisation therefore will require an iterative feedback process between these three elements to determine the most balanced outcome.

2.3.2 Stage 3: Organizational

2.3.2.1 Governance, ownership & management structures

Section 2.2.2.1 discussed some of the common governance, ownership & management structures utilised in off-grid or edge-of-grid power systems, however not all possible structures were covered. There is considerable space for innovation in this space and the most suitable setup will be dependent on many factors, some of which include the site itself, the stakeholders, and the funding/financing , etc.

Whatever the approach taken, the end result must provide a workable and sustainable governance structure that includes the following key features:

- **Clearly defined ownership structure for the system, the land and infrastructure**
    - This structure must cover the entire project life and end of life (EOL)

- **Clearly defined roles and responsibilities for the management of the system**
    - Technical/Engineering/Project management:

        - System design
        - Contracts and procurement
        - Installation and commissioning
        - Quality assurance
        - Safety in design
        - Operation and maintenance
    - Financial management
        - CAPEX/OPEX financing (managing grants, servicing loans , etc.)
        - Operations & maintenance:
            - Revenue (electricity sales, community contributions, renewable energy certificates, carbon offsets , etc.)
            - Expenditures (wages, repairs, replacements, fuel , etc.)
        - Incorporation requirements
        - Taxation compliance
        - Auditing
    - End user engagement and agreements
        - Service obligations of power provider
        - Revenue collection

- **Stakeholder commitment and requirements**
    - It is critical to project success that any stakeholder who is allocated or accepts any of these project roles is fully aware of the implications of their commitment and the capacity to fulfil the role. A general willingness on its own is not sufficient. A party who takes on one or more of these project roles must meet the following requirements:
        - A clear understanding of the role including:
            - the project responsibilities associated with the role
            - the required resourcing (time, money, skills , etc.)
            - the relationship to other project roles and stakeholders
            - the legal implications
        - The internal capacity/capabilities to manage the role and/or
        - The capacity to successfully outsource the parts of the role to more capable external parties
    - Any failure to meet these key requirements will increase the project risk and may lead to future abandonment by the stakeholder of their responsibilities.

- **Capacity building and support**
    - As noted, where project stakeholders are taking on governance roles for the power system there must be an associated requirement that the stakeholder has the capacity to successfully fulfil the associated responsibilities. Any gaps in stakeholder capacity create a significant risk to the project and sustainable strategies must be developed to fill the identified capacity gaps, through either building the required stakeholder capacity directly or engaging other parties to provide the required support on an ongoing basis. The potential time and cost associated with this capacity building should be incorporated into the project planning and financial arrangements.

2.3.2.2 Legal & regulatory frameworks

Having gathered information in the previous stage on the important legal and regulatory frameworks for the deployment and operation of off-grid or edge-of-grid power systems, the key activity in Stage 3 is to sort and analyse the gathered information to then determine suitable legal and regulatory requirements.

The outcomes for this work are:

- **Legal requirements:** To understand the legal/contractual requirements that are most suited to the proposed system governance and management structure. This typically involves determining (at least in outline) the required legal/contractual structures for:
    - System ownership (single, joint, community, commercial, lease , etc.)
    - System financing (loans, grants , etc.)
    - Land use
    - Sale of electricity or energy services
        - Offtake agreement
        - User service agreements & tariffs
        - Performance agreements
    - Connection/network agreements (for edge-of-grid systems)
    - EPC tendering and contracts
    - O&M tendering and contracts

  Because the project is only at the feasibility stage there is no expectation or need for these legal requirements to be implemented at this point. The main purpose of this determination is to identify legal/contractual requirements and understand what their implications will be to the project in terms of time, cost and stakeholder commitment and capacity.

- **Regulatory requirements:** To understand both the general and specific regulatory requirements that apply to the proposed project, the project site, the system design, the system deployment and the system governance and management structures. As these key elements of the project such as site location, system design and the system governance/management structure are being finalized it is important that the associated regulatory requirements be determined in parallel. Compliance with the regulatory requirements will, in most projects, be relatively straightforward. However, this might not always be the case, particularly where innovation is pushing the boundaries of the regulatory environment (e.g. deploying emerging technologies or non-conventional governance structures).

  Typical regulatory requirements for off-grid or edge-of-grid systems include:
    - Development approvals
    - Zoning and land access
    - Environmental, gender equity, and social impact assessments
    - Certifications (e.g. structural, electrical , etc.)
    - Technical approvals and requirements
    - Network connection (edge-of-grid)
    - System design requirements (e.g. from utilities or others)
    - Tariffs and energy service quality requirements

    - Tariff structures, metering and billing requirements
    - Power quality requirements:
        - Standards
        - Quality assurance
    - Local and/or international installation and quality standards
    - Required quality systems for project participants
    - Work health and safety standards

  The main purpose of this activity is to identify the key regulatory requirements that apply to the project and understand what their implications will be to the project in terms of time, cost and stakeholder commitment and capacity. These impacts of the regulatory requirements on the project must be then factored back into the technical and financial analysis

2.3.2.3 Market analysis, supply chains and procurement

The key activity for this section is to analyse the information gathered in the previous project stage and complete a general market assessment in the context of the project site, location, design & deployment, operation and maintenance and governance. A good understanding of the market, its strength, and limitations in the delivery of services related to off-grid/edge-of-grid power systems will greatly improve estimations of the time and cost of both system deployment and system operation and maintenance. It will also help to identify any critical gaps in the market capacity and allow strategies to be deployed within the feasibility to fill these gaps.

The market analysis should aim to address the following areas:

- Projected system costs and practical timelines for the supply and delivery of:
    - System hardware
    - EPC services
    - O&M services
- The availability of suitable project hardware and equipment including:
    - Technical details
    - Component lifetime and associated warranty conditions
    - Availability of ongoing product support
- Delivery logistics for hardware or services to difficult and/or remote locations
- Capacity of existing supply chains to deliver both EPC and O&M services
- The scope for building additional capacity where gaps are identified
- Identifying available incentives for supply chain development and support

The purpose of the market analysis is to determine outcomes for the following:

- Governance: Assist the selection of suitable EPC & O&M contractors, by identifying the existing market capacity to deliver these services, any gaps in this capacity that will impact the project and possible mechanisms for building additional capacity to fill such gaps.

- Technical: A basic requirement of the power system design is that there is suitable equipment available to meet the needs of the design. Suitability of the equipment depends on the design context but generally includes many of the following; minimum requirements availability, interoperability, portability, affordability, reasonable warranty conditions and access to long term support of key system hardware.

- Financial: The financial modelling relies on a wide range of input values. The market analysis provides an opportunity to get up-to-date figures on the:
    - Project costs associated with the design, deployment and ongoing operation and maintenance.
    - Temporal data (e.g. equipment lifetimes, warranty periods, maintenance schedules , etc.).
    - Industry expected values for financial figures (e.g. inflation, rates of return, discount rates , etc.)

2.3.3 Stage 3: Technical

2.3.3.1 Overview

Stage 3 of the technical works for the feasibility study encompasses all matters related to the technical design of the power system and the associated modelling of the designed system.

The end goals of the design, modelling and analysis in this stage are:

- A technical design for the proposed system
- Understanding how the system design impacts the organisational aspects of the projects in terms of O&M, procurement, and capacity building requirements
- Understanding how the system will operate throughout its lifecycle and over a range of conditions
- Create technical outputs required for financial modelling (e.g. energy dispatch summary, fuel consumption , etc.)

The level of detail required in both the system design and modelling will relate directly to the nature and extent of feasibility study. For a scoping study the design and modelling required will be rudimentary, whereas a detailed feasibility study will require the design to be detailed and the modelling to be comprehensive.

The design and modelling are strongly interdependent activities, each informs the other and this iterative relationship and the associated feedback loops is the process by which the system design can be optimised to best meet the technical and financial requirements of the proposed system.

2.3.3.2 System design

The design of off-grid and edge-of-grid power systems is a reasonably complex undertaking, the detail for which is largely beyond the scope of this blueprint. However, the following aspects of the power system design should be noted and understood in the context of this blueprint.

System Size and Capacity

Off-grid and edge-of-grid power systems range in size from small residential-scale systems, right up to large systems with their own high voltage network that power entire towns and/or mine sites. In practical terms the key determinants of the system size are:

- The electrical load characteristics:
    - Power and energy consumption requirements
    - Power factor requirements
    - Load profile (daily, seasonally, annually)

    - Types of loads
- Geographic characteristics:
    - Size of site
    - Physical dispersion of the load
    - Availability of land
    - Site accessibility
    - Availability of renewable resource
- End user requirements and characteristics:
    - Constant power (i.e. 24 hours a day)
    - Tolerance of power outages

System Composition

The major subsystems of an off-grid or edge-of-grid system include:

- Power generation (e.g. hydro, wind, thermal (diesel/gas) , etc.
- Energy storage (e.g. battery energy storage system (BESS), hydro , etc.)
- Power conditioning (e.g. PV inverters, inverter/chargers , etc.)
- System control and monitoring (e.g. SCADA, metering, BMS's , etc.)
- Power distribution (e.g. ancillary services, LV/MV/HV networks and network connections , etc.)
- End use: consumer connections, switchboards, and metering.
- Protection Systems

Design Considerations

When designing an off-grid or edge-of-grid power system there are a range of general technical considerations that need to be addressed to ensure the design suits the requirements of the site and the project stakeholders. These considerations are outlined in Table 7 below.

Table 7. General technical considerations

Consideration	Approach
Reliability	The designed system must provide a reliable power supply. Reliability being measured in terms of the system's capacity to meet demand, maintain a very high level of availability (minimize outages) and deliver power quality within the required standards.
Operating flexibility and efficiency	System configurations and component sizing and selection aimed at ensuring both operational flexibility and efficiency. This includes the selection of low load generators (can run at a loading as low as 10-15%) where available and the mixed sizing of primary generation units to allow efficient matching of load to generation
Redundancy	There shall be sufficient backup generation capacity to meet the peak demand. The level of redundancy is typically expressed in terms of N+1 or N+2 capacity, where N is the baseline number of generators and N+1 or N+2 for example referring to the requirement of having 1 or 2 additional generators always on site and available to cover outages and repairs.

	Providing redundancy comes at a cost of additional capital investment and must be weighed against the perceived risk.
Renewable energy integration	Where hybridization of PV generation with gas or diesel generation has been assumed then a strong focus should be placed on ensuring effective integration between the different generation sources. Typically for diesel units the minimum allowed loading is ~30% and for gas units ~45-50%, where low load generating units can run at a loading as low as 10-15%.
Design lifetime	System design and component selection usually aimed at delivering 25 years of useful operation. Replacement costs for key components that have a lifetime <25 years is accounted for within the financial and technical modelling.
Load growth	Factor load growth into modelling. Implement modular equipment to provide flexibility for future load growth and integration of further renewable energy technology. Simplify integration and control systems to allow for easier modifications going forward. Sensitivity analysis of the recommended system design to changes in load should be explored in the modelling stage.
Operation and Maintenance	Ensure design of new system utilises equipment that reduces maintenance. Use generators from same manufacturers to reduce spare components needed to be stored on site, as well as understanding of operation of equipment is simplified.
Environmental Impact	It is important to take basic measures to reduce the impact of the power system on the site environment and on the environment in general. This can include everything minimizing the impact of local fauna and flora, reduction in noise, safe management of fuels and other chemicals and plans for safe disposable of equipment at EOL.
Ambient Environmental Conditions	Design/select generators and other components appropriately to ambient conditions of site, accounting for temperature, altitude, humidity, and the wind region.

2.3.3.3 System Modelling

The starting point of the technical model is to understand the likely electricity consumption over the life of the project. Each different generating technology making up the hybrid power station is then modelled against this electricity consumption profile to understand how each technology contributes to serving the load. Annual energy summaries and operational characteristics are captured in the outputs and then serve as inputs to the financial modelling stage.

Detailed technical modelling should be completed on all possible system design options. This modelling will likely utilise a combination of industry standard technical design tools (e.g., Meteonorm, PVSyst, HOMER , etc.) and possibly any bespoke in-house modelling tools.

There are a range of inputs to the technical model that are required to be developed, some of which include:

- Load profiles (actual load data or formulated from proxy sources)
- Resource data (onsite measured, satellite data, cross referencing sources)
- System design:
  - selection of hardware and key components
  - system configuration (centralized vs distributed, AC vs DC coupled , etc)
  - network configuration
  - site layout
  - consider options for integrating other renewables with PV (wind, hydro , etc)
- Operational strategies

2.3.3.4 Technical modelling software

Table 8 outlines some of the commonly used technical modelling and optimisation tools used to model the operations of off-grid and edge-of-grid hybrid power stations. In some contexts, the software outlined in Table 8 may not be appropriate and/or won't be able to serve the needs of clients. It is possible to program in-house modelling software tools that utilise open-source programming languages that can do so instead. These tools can be difficult and timely to create and implement, however once implemented, can allow for significant flexibility in the modelling process to allow for tailoring to specific client needs.

Where financial modelling is incorporated into software packages, often it can be either too simplified or integrated in a way that doesn't allow for the required sensitivity and optimisation techniques to be applied that are required to determine the outputs needed to inform appropriate recommendations.

Table 8. Various modelling and optimization tools

Model	Description	Simulation	Operation Optimization	Investment Optimization
AIM/End-use	Cost minimization modelling tool for energy planning		✓	✓
ASIM	Simulates solar/diesel power system operations and conducts analysis of its technical and financial performance, ideal for system design	✓		
FINPLAN (Financial Analysis of Electric Sector Expansion Plans)	Assesses the financial viability of projects, considering financial sources			✓
GEOSIM	Determines the most cost-effective electricity generation options			✓
HOMER (Hybrid Optimization of Multiple Energy Resources)	Handles grid and off-grid systems	✓	✓	✓

Model	Description	Simulation	Operation Optimization	Investment Optimization
LEAP (Long Range Energy Alternatives Planning)	Modelling tool used to track energy consumption, production, and resource extraction	✓		✓
MARKAL/ TIMES	Economic-environmental optimization model for least-cost planning of energy systems			✓
GIZ (Deutsche Geselleschaft fur Internationale Zusammenarbeit) Mini-grid Builder	Performs energy demand calculations and required generation capacity	✓		
MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact)	Medium-to long-term energy system planning, energy policy analysis and scenario development		✓	✓
Network Planner	Used for least-cost planning for grid, mini-grid, and off-grid systems			✓
Paladin DesignBase	Simulation platform for modelling, analysing, and optimizing power system performance	✓	✓	
RETScreen	Used to determine whether a proposed renewable energy, or energy efficiency project is financially viable	✓		
REDEO (Rural Electrification Decentralized Energy Options)	Handles off-grid systems used to compare various distributed power generation options	✓		
WASP (Wien Automatic System Planning)	Expansion plan optimization model for electricity generation	✓	✓	✓
INSEL (Integrated Simulation Environment Language)	Simulation program for grid-connected and stand-alone PV systems	✓	✓	

2.3.3.5 Inputs to the technical model

Electricity consumption profile

One of the first steps in the technical modelling process is to first understand how the site consumes electricity over the life of the project. For the purposes of modelling, the typical life of an off-grid hybrid power station is assumed to sit somewhere between 25 – 30 years. Therefore, while the current patterns of electricity consumption need to be understood, there also needs to be understanding on how electricity will be consumed into the future.

Some of the initial questions that need answering are whether electricity consumption data is being recorded, can it be recorded, and is there access to a repository of historical data. While the context of place can change rapidly and present circumstances do not always best represent the future, often historical electricity consumption data can provide useful insights into the patterns of electricity consumption, which is vital information to feed the technical model.

Accessible load data

The easiest and quickest way to understand how electricity is being consumed is to have access to electricity consumption data. The data needs to have relatively consistent records over short timeframes (e.g., 5-minute, 1-hour) to be sure how the profile changes throughout the day and across the different seasons. Usually, at a minimum, at least one full year of data at hourly resolution is required to accurately determine how electricity is consumed at a site. If multiple years of electricity consumption data are available, it will be useful to understand how electricity consumption has changed over historical years. If a trend can be found and aligned with population estimates or infrastructure upgrades, then a reasonable understanding can be had on what key aspects influence electricity consumption. Then, after extensive engagement with the community, reasonable assumptions can be made about how the electricity consumption may change in the years to come.

This information and engagement with community allows for a multi-year (e.g., 25 years) electricity demand forecast to be determined, which accounts for all changing variables within the community that impact electricity consumption (e.g., population, infrastructure upgrades, climate, transient populations, tourism periods , etc.).

No accessible load data

Often data is not recorded and not available, particularly at remote locations. Sometimes data is recorded, however large periods may be missing or incorrectly recorded. If no useful historical electricity consumption data is accessible, then consumer patterns of electricity consumption must be understood through extensive engagement with the community and through electrical site assessments.

Engagement with consumers provides valuable opportunities to ask questions, learn, educate, and form relationships. The opportunities can lead to vital information being captured that ultimately feeds the technical modelling stage of a feasibility study.

By completing a load assessment of each individual building in the community, a net community load upon which to base the sizing of the SPS can be formed. The electricity consumption can be represented using the following parameters:

- Total volume of the community load (kWh/day),
- The daily demand profile (kW),
- The seasonal demand profile (kW/kWh)

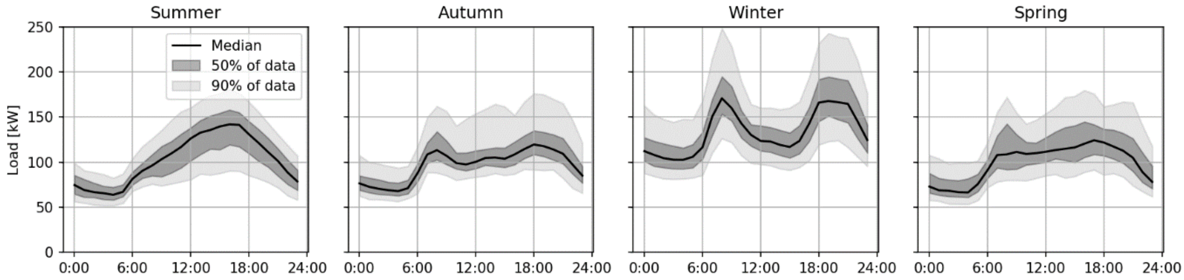

Figure 3. Example of a seasonal load profile, including showing the distribution.

Determining the size and electricity profile of a community load can be complicated and it is important to understand context. The average daily electricity consumption of a typical urban and grid-connected household is likely to be very different to that in remote communities. Consumption in remote, off-grid contexts, may be subject to additional factors such as limits on access to alternative fuels (e.g. gas for cooking), reduced incomes and capacity to pay for electricity, and poorer quality housing - which has a strong impact on the effectiveness of cooling and heating loads.

As a rule of thumb, it may be useful for readers to note that as a baseline, the provision of 10-15 kWh per day of electricity to a three or four-bedroom household would be sufficient to run the following typical loads:

- Refrigerator: good quality, energy efficient and affordable model with working seals
- Chest freezer: good quality, energy efficient and affordable model with working seals
- Household lighting: all rooms
- Ceiling fans: bedrooms and living spaces
- Cooking appliances: kettle, toaster and electric fry pan
- Pressure pump
- Washing machine
- Entertainment: TV, stereo, radio

These loads represent a baseline electricity requirement. Some common loads that are missing from this list are electric hot water heating, electric stoves, and air conditioning. These loads are all significant consumers of electricity. Between them they can easily add another 10 to 20 kWh per day in electricity demand per household. Generally, it is not cost-effective to use PV and BESS based systems to meet such loads. Where possible, alternatives such as solar or gas water heating, gas cooking and fans should be deployed. If this is not possible then full hybrid integration of a diesel generator into the SPS to manage this high demand is usually the most cost-effective approach.

Some feasibilities are conducted as desktop studies, where no site visit takes place, and all information is gathered remotely. However, even where historical electrical consumption data exists, some form of engagement with the target community is a fundamental requirement to understanding how the electricity demand might change into the future. The engagement process also provides an opportunity to explain the proposal to the community and understand the community's particular circumstances and thereby ensure the hybrid system design meets the needs and capabilities available to operate and maintain the system. If a site visit does occur, community engagement is generally carried out alongside a full site assessment in which the information required to feed into the system design and procurement stages is also gathered.

Renewable energy resource

PV systems generate all their power through the conversion of sunlight into electricity. The more sunlight, or solar insolation, that is available the larger the amount of electricity generated. Solar insolation is a measure of the solar energy that falls on a given area over a defined time period and is the key parameter for determining the generating potential for photovoltaic power systems.

Even in regions well-suited to solar, there may be considerable variability in annual insolation from year to year. In the context of feasibility simulation, the long-term annual mean, also known as the P50 value, is typically used. In the context of a risk-sensitive bankable financial assessment, a P90 reference is also considered. A P90 value represents an annual insolation level that is expected to be exceeded with 90 percent probability in any given year.

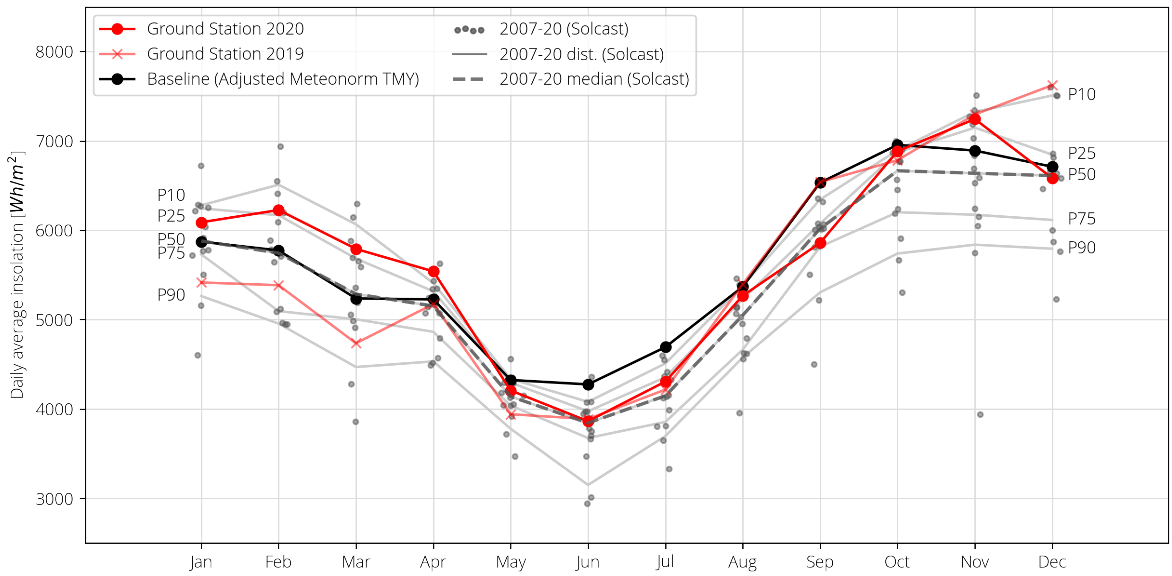

Figure 4. Example image displaying the difference in daily average insolation values across each month of historical data from multiple sources of solar resource data (i.e. ground weather station, Meteonorm, and Solcast). The solid grey lines indicate different probability of exceedance values.

The historical energy resource must be well understood to estimate what energy generation can be expected from different renewable generating technologies across the project's lifetime. Historical solar resource data can be gathered from many and varied sources.

Once a reasonable estimation of the renewable energy resources is known, it is used as an input to the technical modelling stage to simulate the generation profile of the respective renewable energy technology.

Generator technologies

The equipment that generates electricity in off-grid and edge-of-grid communities is generally limited to conventional generators and/or renewable energy generation via PV modules, wind turbines or hydro-power turbines.

Conventional generation refers to petrol, diesel and/or gas-fired generators. These technologies are generally well understood and, when well-fuelled and maintained, can provide reliable power. Compared to the renewable alternative, they have low capital costs but high running costs due to their fuel consumption and regular maintenance requirements.

Conventional generators can be found in some form in nearly all stand-alone power systems, used as either:

- The primary source of power
- An integrated part of a hybrid system, or
- A backup generator

Renewable energy generation can come in many forms, but the most applied technologies include solar PV, wind, and hydro-power turbines. In many off-grid and edge-of-grid power systems, solar PV offers a cost-effective form of generation that can support and/or largely replace existing conventional generation. These power systems typically include a combination of PV, BESS and conventional generation.

Solar PV can be installed as either flat plate PV modules on fixed ground-mounted or roof-mounted array frames, or more complicated but higher yielding tracking PV systems. Tracking PV systems are more commonly used on utility-scale sized systems as the additional cost implementation and operational costs fall with economies of scale and are recouped by the relatively larger yield per unit of capacity installed. A critical consideration when deciding on a fixed vs. tracking system is to understand how the asset will be managed and operated. Tracking systems involve more moving parts and therefore encounter more frequent issues during operations. Asset managers and operators need to be able to access the site frequently and have a good understanding of how to maintain these systems. It is recommended that a simpler fixed solar PV installation is applied in any remote off-grid or edge-of-grid site that is difficult to access and/or doesn't have sufficient asset management teams in place to ensure immediate rectification issues.

An obvious downside of PV technology is not being able to generate power at night, or during periods of extended overcast weather. In stand-alone power systems (SPS) this issue is overcome by coupling the PV with an energy storage system, which allows the PV-generated energy to be stored for later use.

Once there is an understanding of the electricity consumption profile, renewable energy resource, and the local context, a shortlist can be made of the appropriate generating technologies. The operational characteristics of each generating technology will be required as inputs into the technical model. The following factors need considering when deciding on which technologies to include in the power system design:

- The level of the available resource (e.g. sun, wind, water flow)
- Capital and operational expenditure
- Reliability, complexity, and scalability

Operational constraints

Typically, it is estimated within technical and financial models that the overall lifetime of a hybrid power station lasts somewhere between 25-30 years. However, not all technologies included within the power system are expected to last that long. For a hybrid power system to continue to operate for as long as is expected, each technology component must be maintained and, when required, replaced.

The expected lifetime changes for different technical components and are impacted by the operational conditions (e.g. climate, maximum power discharge, ramp rates, hours of operation, energy throughput , etc.). Often the manufacturer of key technical equipment will provide warranties on products assuming they are operating within pre-stated boundaries (e.g. temperature). Some of the common operational lifetime expectations for key technical equipment in a hybrid power station are listed in Table 10.

Table 9. Common operational lifetime assumptions for key technical components

Component	Expected Lifetime
Hybrid Power Station	20 - 30 years
Solar PV modules	+ 25 years
Wind turbines	+ 25 years
Inverters	10 - 15 years
BESS	8 - 15 years (highly dependent on operation)
Diesel / gas generators	20,000 – 50,000 hours (highly dependent on operation

Below is a list of some of the critical operational constraints that need accounting for to accurately simulate the operations of a hybrid power station in the technical model:

- Level of redundancy (e.g. N+1, N+2)
- Solar PV coverage ratio: Proportion of the system area that is used to collect sunlight
- Spinning reserve: the available spare power in the system.
- Step load: the capability to take a single immediate increase in load.
- Conventional generator start time: the time taken to turn on a generator
- Conventional generation minimum loading constraints
- Battery recommended maximum depth of discharge
- Battery allowable peak discharge
- Allowable ramp rate for entire power system and individual generating technologies
- Level of fuel reserves for conventional generation
- Maximum allowable runtime hours for conventional generators before scheduled maintenance and/or major overhauls are required

Several of the operational constraints above will change depending on the context in which the power system is applied.

2.3.3.6 Outputs to the technical model

Annual energy dispatch summaries

Generally, the technical modelling of the power system occurs prior to the financial modelling stage. This is because several outputs from the technical modelling stage are required as inputs to the financial model. For example, the financial model needs to know information pertaining to the technology type and size of components installed (e.g. solar PV and battery capacity), the energy dispatch summaries (e.g. fuel consumption, renewable energy fraction), and the operational maintenance required on the system (e.g. diesel generator runtime house). This information is all collected by simulating the operations of the proposed hybrid power station using computer software. A list of the common types of software utilised to conduct technical modelling are provided in the Literature Review section of this report.

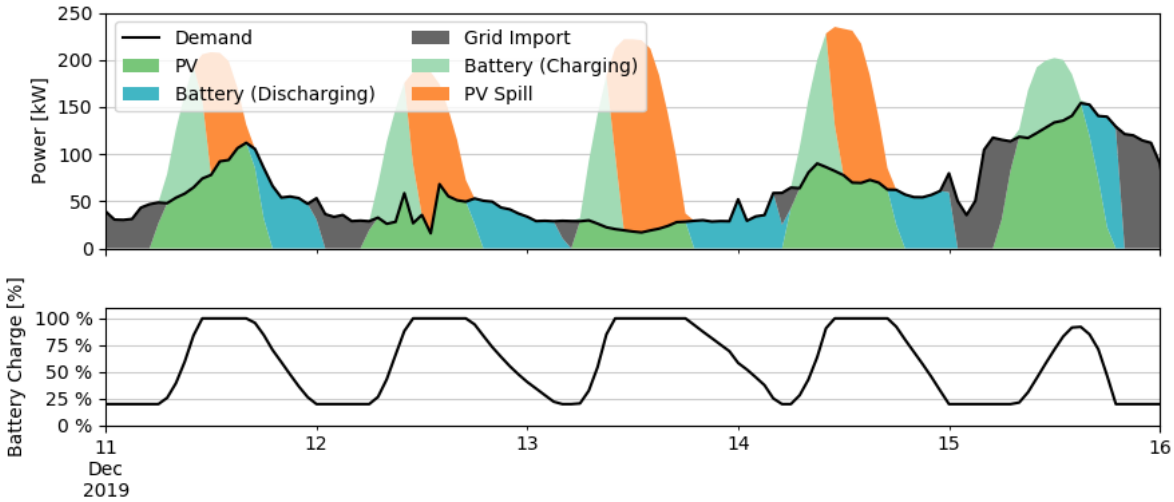

Figure 5. Exemple image visually demonstrating energy being dispatched and/or spilled from each technology in the technical modelling stage.

Sometimes a feasibility study is carried out already knowing the exact design of the power system, with technologies and size of components known. In this case, it may only be required to run the technical model once to generate the outputs required to conduct financial modelling. Alternatively, and often is the case in the pre-feasibility stage, the exact design of the power system is not known, and the purpose of the feasibility study is to determine this. In this case, the technical model may be run over multiple (e.g. tens, hundreds, or even thousands) designs. Having access to the outputs across many different technical models, and subsequently, financial models, allows for an optimal final design to be selected that considers all the pre-identified metrics for success for the project (i.e. renewable energy fraction, maximising financial return, minimising ongoing operational expenditure , etc.).

Further, where sensitivity analysis is to be undertaken to identify if any major risks that exist for particular variables of the project (e.g. diesel generator minimum loading, BESS round trip efficiency, diesel fuel price , etc.), it will also be required to run additional technical and financial models to then analyse how the outputs change when certain variables are adjusted.

While the technical model and financial model sit separate to one another, some the common inputs required for both models are in Table 11. In a situation where the final design of the power station is not known and this is to be determined by the feasibility study, then the variables in Table 11 may be returned as outputs from the technical modelling stage. This section provides a general overview of the common inputs required to the financial modelling stage.

Table 10. Common static inputs that serve both the technical model and financial model

Variable	Notes
Solar PV size [kW_{DC}]	Solar PV nominal DC capacity
DC:AC Ratio	The inverter's The DC to AC ratio
Solar PV size [kW_{AC}]	Solar PV nominal AC capacity
Inverters [kW]	Total size of inverters installed
Battery size [kW]	Power rating of battery
Battery size [kWh]	Energy rating of battery
Diesel gen 1 size [kW]	Diesel genset 1 capacity
Diesel gen 2 size [kW]	Diesel genset 2 capacity
Diesel gen 3 size [kW]	Diesel genset 3 capacity

Table 12 provides examples of the common energy dispatch summary information that are generated as outputs from technical modelling and used as inputs to the financial model. The energy dispatch summaries quantify how each technology in the power system contributed energy to serving the load over a given time frame. Monthly, quarterly and annual timeframes are most commonly used when summarising energy dispatch. The list provided in Table 12 is an example only and may change depending on the power system technologies utilised and the context in which the project is applied.

Table 11. Examples of common technical modelling output variables required for financial modelling

Variable	Year 1	Year 2	Year 3	…	Year 25
Annual energy dispatch summary					
Solar PV total production [kWh]	#	#	#	#	#
Solar PV spill [kWh]	#	#	#	#	#
BESS energy in [kWh]	#	#	#	#	#
BESS energy out [kWh]	#	#	#	#	#
Solar PV serving load [kWh]	#	#	#	#	#
DG1 generation [kWh]	#	#	#	#	#
DG2 generation [kWh]	#	#	#	#	#
DG3 generation [kWh]	#	#	#	#	#
Total energy to load [kWh]	#	#	#	#	#
Annual energy dispatch summary					
DG1 fuel consumption [litres]	#	#	#	#	#

DG2 fuel consumption [litres]	#	#	#	#	#
DG3 fuel consumption [litres]	#	#	#	#	#
DG1 hours of operation [hours]	#	#	#	#	#
DG2 hours of operation [hours]	#	#	#	#	#
DG3 hours of operation [hours]	#	#	#	#	#
Emissions summary					
Emissions (e.g. CO_2, CO , etc.)	#	#	#	#	#

2.3.4 Stage 3: Financial

This stage of the Blueprint requires a financial model to be developed and run, and for the financial modelling outputs to be analysed, summarised, and clearly presented. Sensitivity analysis highlights if any variables pose financial risk to the project. Where significant sensitivities are identified, revisiting the technical modelling stage and altering the design may be necessary to manage these risks. Effectively communicating the output from financial modelling can be a tricky process to navigate. Simple language and data visualisations often aid this process. It's important to understand and be able to summarise the financial situation from the perspective of each stakeholder.

Financial models vary greatly in the level of detail and complexity involved which usually depends on the project, and the nature and type of feasibility being conducted. For instance, a relatively simple financial model may be suitable for a pre-feasibility study, whereas reaching financial close on a large project with numerous debt and equity providers will require a much more detailed financial model. It's not appropriate in this report to go into detail exploring all the types of financial models, rather, what's critical is that readers understand the core purpose of a financial model, how they function, and what outputs are expected. The goal of the financial modelling process is to quantify the overall feasibility of a project, in monetary terms, from the perspective of all invested stakeholders, and provide a breakdown of the cash flow statement throughout a project's lifecycle.

The steps in this stage of the Blueprint can be summarised as follows:

- Develop a suitable financial model
- Run the financial model using the inputs gathered from previous stages of the Blueprint
- Analyse the financial modelling outputs
- Conduct sensitivity analysis and identify financial risks for the project
- Identify the optimal technical and financial outcomes for the project, from a monetary perspective

The end goals of the financial modelling/analysis are:

1. Summarise the project's feasibility using the following key metrics
   a. Initial investment required
   b. Levelised cost of electricity (LCOE)
   c. Net present value (NPV)
   d. Internal rate of return (IRR)
   e. Payback period
2. Identify which inputs to the financial and technical model raise the most risk for the feasibility study (e.g. solar generation, fuel price, tariffs, interest rates , etc.)
3. Understand the project's cashflows over its lifecycle (i.e. can cashflow cover REPEX? Are repayments on debt successfully met? When can equity providers expect dividends?)

2.3.4.1 Inputs to financial model

Some of the inputs required to conduct financial modelling that stem from the technical modelling stage have already been identified.

Table 13 outlines some common inputs required for financial modelling that pertain to financing, initial expenses, value propositions, capital CAPEX, and OPEX. Many of the static inputs outlined in Table 13 also require forecasts being applied to them over the project's life cycle. Two types of forecasts are typically applied to variables. Some variables require detailed manual forecasts to be applied that rely on extensive research (e.g. green scheme benefits, diesel fuel price), while others might be better simplified using well-known long-term trends (e.g. inflation). Variables that pose significant financial risk to the project may require detailed, well researched manual forecasts to be applied for each relevant timeframe (e.g. month, quarter, year , etc.). More simplified forecasts can rely on a constant index being applied (e.g. Battery CAPEX decreasing by 5% each year) throughout the project's lifecycle.

Table 12. Common static outputs from the technical model that serve as inputs to the financial model

Variable	Notes
Solar PV size [kW_{DC}]	Solar PV nominal DC capacity
DC:AC Ratio	The DC to AC ratio
Solar PV size [kW_{AC}]	Solar PV nominal AC capacity
Inverters [kW]	Total size of inverters installed
Battery size [kW]	Power rating of battery
Battery size [kWh]	Energy rating of battery
Diesel gen 1 size [kW]	Diesel genset 1 capacity
Diesel gen 2 size [kW]	Diesel genset 2 capacity
Diesel gen 3 size [kW]	Diesel genset 3 capacity

Table 14 provides examples of the common energy dispatch summary information that are generated as outputs f.rom technical modelling and used as inputs to the financial model. The energy dispatch summaries quantify how energy flowed through each technology type in the power system over a given time frame. Monthly, quarterly and annual timeframes are most commonly used when summarising energy dispatch. The list provided in Table 14 is an example only and may change depending on the power system technologies utilised and the context in which the project is applied.

Table 13. Examples of common technical modelling output variables required for financial modelling

Variable	Year 1	Year 2	Year 3	…	Year 25
Annual energy dispatch summary					
Solar PV total production [kWh]	#	#	#	#	#
Solar PV spill [kWh]	#	#	#	#	#
BESS energy in [kWh]	#	#	#	#	#
BESS energy out [kWh]	#	#	#	#	#
Solar PV serving load [kWh]	#	#	#	#	#
DG1 generation [kWh]	#	#	#	#	#
DG2 generation [kWh]	#	#	#	#	#
DG3 generation [kWh]	#	#	#	#	#
Total energy to load [kWh]	#	#	#	#	#
Annual energy dispatch summary					
DG1 fuel consumption [litres]	#	#	#	#	#
DG2 fuel consumption [litres]	#	#	#	#	#
DG3 fuel consumption [litres]	#	#	#	#	#
DG1 hours of operation [hours]	#	#	#	#	#
DG2 hours of operation [hours]	#	#	#	#	#
DG3 hours of operation [hours]	#	#	#	#	#
Emissions summary					
Emissions (e.g. CO_2, CO , etc.)	#	#	#	#	#

Table 15 outlines some common inputs required for financial modelling that pertain to financing, initial expenses, value propositions, CAPEX, OPEX) Any of the inputs outlined in Table 15 might also have values forecast over the project's life cycle. Typical value ranges have been provided for some variables, which are examples only and will change significantly across different projects. These example figures should not be relied upon. Separate research should be conducted on each feasibility study to determine the likely values for each variable.

Table 14. Examples of the common types of financial model inputs required to conduct modelling. Example values provided are in Australian Dollars.

Input	Example of typical value(s)
Financing, inflation and tax rate	
Debt [$]	NA
Equity [$]	NA
Funding [$]	NA
Total investment [$]	NA
Cost of debt [%]	3-5%
Cost of equity [%]	6-14%
Loan tenure (years)	5-25 years
Inflation [%]	1-4%
Tax rate [%]	0-50%
Debt to value ratio [%]	60-90%
Weighted Average Cost of Capital [%]	3-8%
Initial expenses	
Project management and engineering [% of CAPEX]	1-6%
Contingency [% of CAPEX]	0-10%
Development fees [% of CAPEX]	1-3%
Prices associated with possible value streams	
Electricity price [$/kWh]	$0.25
Diesel price [$/litre]	$0.80 - $2.00
Capital expenditure	
Solar PV [$/W]	$0.80 - $3.00
Inverter [$/W$_{AC}$]	$0.05 - $0.15
BESS [$/kW]	NA
BESS [$/kWh]	NA
DG1 [$]	NA

DG2 [$]	NA
DG3 [$]	NA
Network [$]	NA
Fixed capital [$/kW]	NA
Operational expenditure	
Solar PV OPEX per W_{DC} [$/$W_{DC}$]	$0.1 – $0.03
Inverter operational life [years]	15 years
BESS OPEX per kWh [$/kW]	$12
BESS operational life [years]	8 – 15 years [depends on many factors]
Diesel generator maintenance [$/kW/hour]	$0.01 – $0.04
Maximum diesel generator runtime [hours]	15,000 – 50,000
Network annual OPEX [$]	NA

2.3.4.2 Outputs from financial model

The variables commonly relied upon to succinctly summarise the financial modelling stage include:

- Initial Investment: the amount of upfront investment required, which may change for each invested stakeholder
- Levelised Cost of Electricity (LCOE): the lifecycle cost of energy generated by the power system in present value (i.e. future costs discounted back to represent the cost today), usually represented as a dollar per unit of energy generated.
- Net Present Value (NPV): the total profit or loss of the project in present value terms (i.e. future cashflows discounted back to represent the value in monetary terms today).
- Internal Rate of Return (IRR): this is a common benchmarking metric used to compare investments and represents the rate at which future cashflows need to be discounted by to make the NPV equal to zero. The higher the IRR, the better a project's return is.
- Payback period: the amount of time, usually in years, taken to recoup an initial investment. The payback period may change for different invested stakeholders.

More information related to the above metrics are provided below.

Initial investment

The initial investment is the total investment required to fund the initial stages of the project, including covering capital expenditure. All investments typically expect a return, and therefore any funding and/or grants are not usually considered a part of the initial investment, however these contributions are captured in the total project cost. The total initial project investment will likely be the sum of all debt and equity invested.

Levelised costs of electricity

The Levelized Cost of Electricity (LCOE) represents the long-run marginal cost of electricity generation and is calculated using Equation 1. Energy generation in the denominator of Equation 1 is discounted, as opposed to using the total energy over the project's lifetime. This methodology is consistent with the standard employed by Australian Government agencies, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Renewable Energy Agency (ARENA).

Equation 1. Levelised Cost of Electricity

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

Where:

- $LCOE$ is the Levelised cost of electricity.
- I_t is the Capital investment expenditure (CAPEX) in year t, Including the book value of existing assets, as well as overhaul and replacement of assets throughout the project lifetime.
- O_t is O&M expenditure (OPEX) in the year t, including asset maintenance, fuel usage priced at the forecast assumptions as well as fixed operating costs which include labour and facilities, insurance and land lease costs.
- E_t is Electricity generation in the year t. Includes all energy delivered to the load.
- r is Discount rate, set to the post-tax WACC in this analysis.
- n is Project lifetime in years, assumed to be 25.

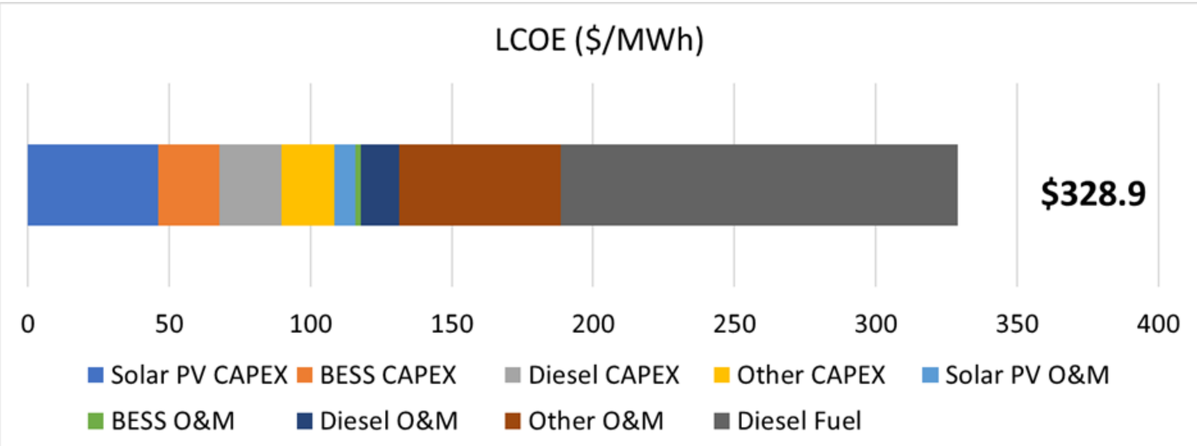

Figure 6. Example image showing a common breakdown of LCOE

Net Present Value

Common to all project financial models is the discounted cash flow (DCF) statement. The DCF values a project based on the present value (i.e. monetary value reflective of the present time) of its cash flows. The Net Present Value (NPV) is calculated by discounting the free cash flows using an appropriate discount rate. First, the free cash flows are projected out using assumptions for revenue growth and expenses, and each year a free cash flow is calculated, which is then summed and discounted to a NPV, based on the appropriate discount rate.

The steps involved in calculating the free cash flows each year can be summarised as follows:

1. Earnings Before Interest, Tax, Depreciation and Amortisation (EBITDA)
   a. Calculate EBITDA by subtracting operating expenses (excluding depreciation and other non-cash expenses) from revenue.
2. Earnings Before Interest, Tax (EBIT)
   a. Calculate EBIT by subtracting depreciation and other non-cash expenses from EBITDA
3. Earnings Before Tax (EBT)
   a. Subtract debt repayments from EBIT.
4. **Unlevered free cash flow (project cash flow)**
   a. Multiply EBIT by one minus the tax rate (e.g. 1 – tax rate), add back depreciation and other non-cash expenses, subtract capital expenditure.
   b. The discount rate applied to unlevered cash flows to get the project NPV is typically the weighted average cost of capital (WACC).
5. **Levered free cash flow (equity cash flow)**
   a. Multiply EBT by one minus the tax rate (e.g. 1 – tax rate), add back depreciation and other non-cash expenses, subtract capital expenditure.
   b. Levered free cash flow is the equity value, since the cash flow is only available to equity investors (debt investors have already been paid with interest payments).
   c. The discount rate applied to levered cash flows to get the equity Net Present Value (NPV) should be the cost of equity, rather than the weighted average cost of capital (WACC), since this is not concerned with debt.

Equation 2. Project Net Present Value

$$Project\ NPV = \sum_{t=1}^{n} \frac{Unlevered\ cash\ flow_t}{(1+WACC)^t}$$

Equation 3. Equity Net Present Value

$$Equity\ NPV = \sum_{t=1}^{n} \frac{Levered\ cash\ flow_t}{(1+cost\ of\ equity)^t}$$

Where in Equation 2 and Equation 3:

- NPV is the Net Present Value.
- $Unlevered\ cash\ flow$ is the project's value, since the cash flow is available to both debt and equity investors.
- $Levered\ cash\ flow$ is the equity value, since the cash flow is only available to equity investors (debt investors have already been paid with interest payments).
- $WACC$ is the weighted average cost of capital and is the rate at which project cash flows are discounted to get values in present terms.
- $cost\ of\ equity$ is the amount that equity holders expect in return for providing equity funding. Returns on equity are paid out from profits, after the majority owners, or boards, have decided what amount to retain for reinvestment or emergencies. For

these reasons, equity investments are considered riskier than debt and demand relatively higher returns.

- n is the project's lifetime in years, assumed to be 25.

Internal Rate of Return

The internal rate of return (IRR) is the discount rate that makes the NPV equal to zero in a DCF. The IRR is a metric that estimates the profitability of potential investments. The higher the IRR the more attractive the investment opportunity. The Project IRR is relevant for both debt and equity investors, while the Equity IRR is only relevant for equity investors in a project. The Project and Equity IRR values can be calculated using trial and error (e.g. using Goal Seek in Microsoft Excel) in Equation 4 and Equation 5, respectively.

Equation 4. Project Internal Rate of Return

$$0 = Project\ NPV = \sum_{t=1}^{n} \frac{Unlevered\ cash\ flow_t}{(1 + Project\ IRR)^t}$$

Equation 5. Equity Internal Rate of Return

$$0 = Equity\ NPV = \sum_{t=1}^{n} \frac{Levered\ cash\ flow_t}{(1 + Equity\ IRR)^t}$$

Payback period

The payback period is the amount of time, usually in years, that it takes for an initial investment to be recouped. This can be calculated by keeping track of the cumulative cash flows over time and comparing this to the initial investment.

Optimisation

The optimal design of a power station depends on both the technical and financial modelling. As a result, it is good practice to run the technical and financial model based on numerous scenarios that incorporate different power station designs. This results in numerous feasibility outcomes being generated, each one relevant to the specific inputs that fed into the technical and financial models. An optimal scenario can then be selected by choosing the power system design that generates the desired outcome of the stakeholders.

For example, a business client may wish to install as much solar as possible on their roof. By running numerous simulations throughout the technical and financial models, the analysis stage demonstrates that the client would be better, both from the perspective of profits and returns, to not install as much solar as the roof allows. Figure 7 demonstrates that installing the maximum amount of solar PV on the roof does not maximise the Equity NPV (i.e. profit). Alternatively, and specific to the Australian context, the Equity IRR values are more desirable when the system is eligible to receive STCs (small-scale technology certificates) rather than a larger system receives LGCs (large-generation certificates). If profits are to be maximised, then a solar PV system between approximately 200-250 kW will achieve this. Completely filling the roof with solar PV actually results in the client losing approximately $25,000 over the 25 year life of the project.

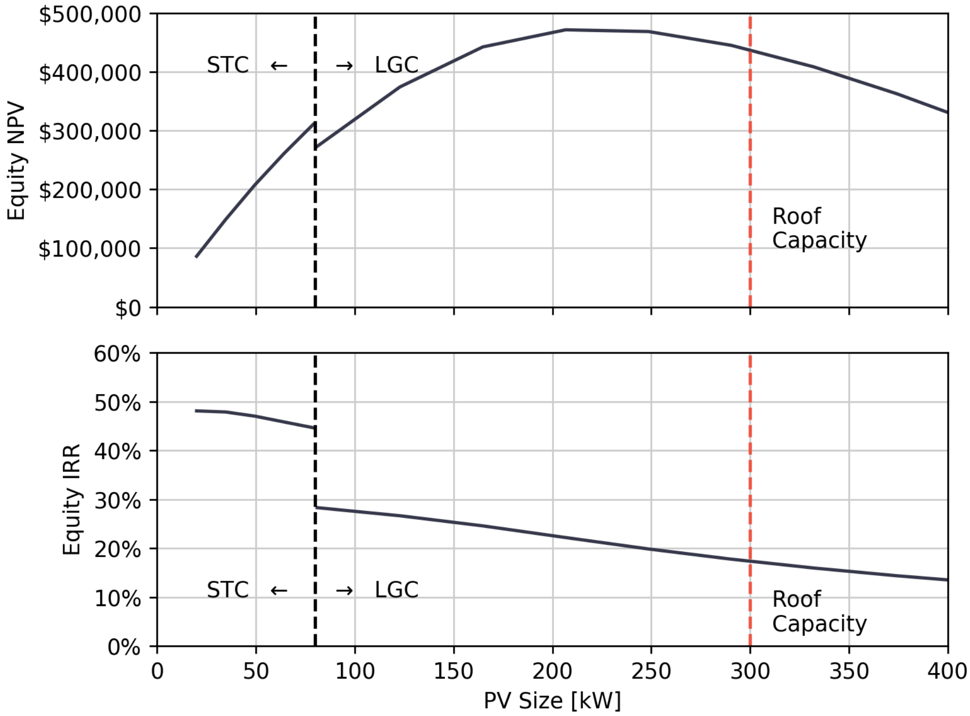

Figure 7. Example image showing how numerous scenarios being run through the technical and financial model allow for certain metrics to be optimised.

2.3.4.3 Sensitivity

Conducting sensitivity analysis determines the effects that changes to input variables have on key financial outputs, such as NPV, IRR and payback period. The outputs from the sensitivity analysis can highlight where key risks exist for a project. Figure 8 shows an example tornado plot for building a front-of-meter solar PV project in Australia. The boxplots demonstrate reasonable distributions for each input variable on the y-axis, and how the IRR of the project changes depending on the value of the input variable.

Figure 8 shows that the four variables introducing the largest sensitivity to the project returns are the electricity price index, electricity starting price, grant funding available to the project, and capital expenditure. This then allows for discussions and plans to be had around managing these risks. For instance, extra work might be invested in establishing secure long-term offtake agreements to reduce the project's exposure to volatile electricity prices. Perhaps additional resources can be directed to engage with Government to better understand the likelihood of receiving grant funding and if so, how much. Further, early engagement with engineering, procurement, and construction contractors might result in initial CAPEX estimates to be established.

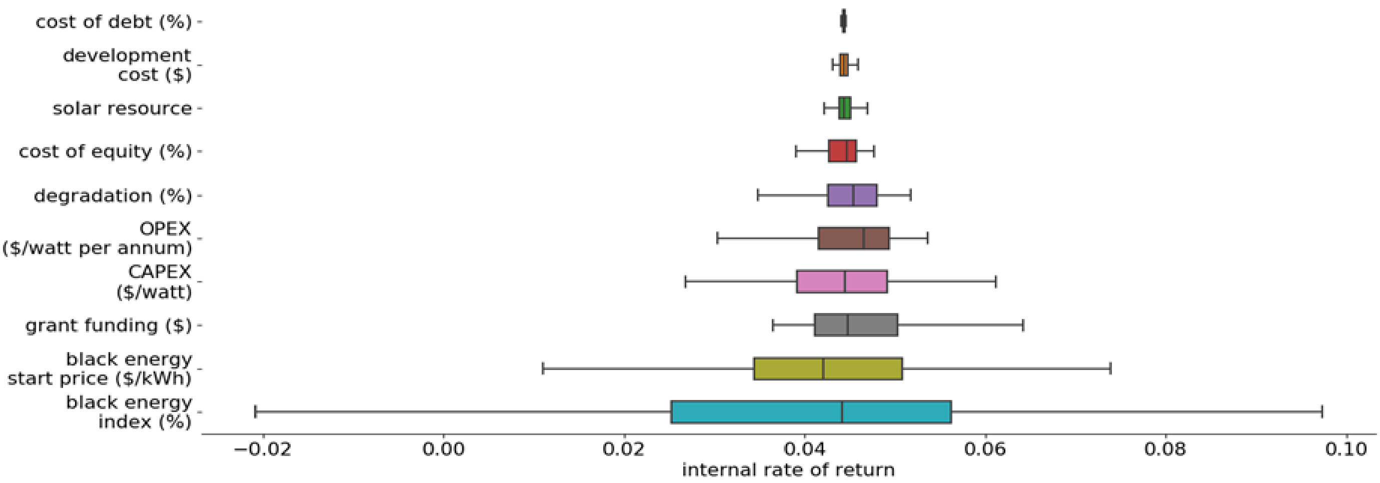

Figure 8. Example image of sensitivity analysis conducted on a front-of-meter solar PV project in Australia

2.4 Stage 4 assessment and recommendation

The objective of the fourth and final stage of this blueprint is to bring together all the analysis and understanding of the organisational, technical, and financial aspects of the project, make an assessment as to the whether the project is "feasible" and provide stakeholders with clear recommendations and guidance on how to proceed. To guide this final stage assessment this blueprint provides a general structure for this assessment, some underlying principles to support the assessment and a range of assessment criteria to be applied against the key project elements.

2.4.1 Assessment approach

This blueprint recommends the following general approach when completing the feasibility assessment:

1. **Separately evaluate each project element**
   Initially, make a separate evaluation for each of the three project elements (i.e. organizational, technical, financial). These individual assessments should:
   - Demonstrate the feasibility or otherwise of the project element against the previously agreed assessment criteria that were determined for each element in Stage 1.
   - Identify strengths.
   - Identify specific areas of project risk and vulnerability.
   - Nominate potential mitigation requirements for managing identified risks and vulnerabilities.

2. **Evaluate the project as a whole**
   Collate the assessments of the individual project elements and determine the overall feasibility of the project. As previously noted, these three project elements are highly interdependent and during Stage 3: modelling and analysis, the iterative design and modelling process should have identified one or more project options that were optimised across the three key project elements. This collective project assessment should:
   - Demonstrate the feasibility or otherwise of the project against the previously agreed assessment criteria.
   - Aim to balance the assessment outcomes for the individual organisational, technical, and financial aspects of the project against the needs of the project.
   - Identify overall project strengths and benefits.
   - Identify the net project risks and vulnerabilities.
   - Nominate potential mitigation requirements for managing identified net risks and vulnerabilities.

3. **Report and document**
   Assemble and organize the feasibility assessment into a format that:
   - Matches the agreed nature and extent of the feasibility report.
   - Clearly articulates the key outcomes of the feasibility assessment.
   - Clearly articulates the key recommendations of the feasibility assessment.
   - Is both accessible and understandable to the target audience.

- Where appropriate, provides workable options and alternatives.

The inclusion or workings, modelling and analysis and the overall complexity of the final documentation should be tailored to the needs of the target audience. In some situations, several different versions of the same feasibility assessment may need to be generated to suit different stakeholders. For example, the project funders may want a feasibility assessment report strongly focused on the financial outcomes of the proposed project, whereas a community who are to receive the energy services would likely prefer a report that talks to the possible benefits of the system, employment opportunities, impacts on electricity tariffs and other more local concerns.

2.4.2 Underlying assessment principles

Regardless of which project element is being assessed, there are some basic principles and considerations that should be universally applied to the feasibility assessment. These include:

1. **Alignment with project aims and objectives**
   Ultimately, the purpose of the proposed project is to achieve the aims and objectives originally identified by the key stakeholders. Therefore, a significant degree of alignment in the anticipated project outcomes with these aims and objectives is a key requirement.
2. **Project sustainability**
   A well designed, installed and maintained PV based off-grid or edge-of-grid power system can expect to achieve a system life of at least 25 years. Ensuring these systems achieve this project life is important for several reasons:
   - Financial return: These power systems typically have high capital costs but low operating costs and the effective payback on the capital investment may take 5 - 10 years to realize. As a result, ensuring these systems operate for their full lifetime provides the greatest economic return.
   - Stakeholder satisfaction: Project stakeholders, and in particular the end user, of the power system has a reasonable expectation that the supplied power will be both reliable and of a suitable quality. Failure in the power system to meet these expectations will result in a general disenchantment, complaints, legal action, withheld payments and resistance to future projects of a similar nature.
3. **Stakeholders understanding and in agreement**
   For the project feasibility to have a meaningful and successful outcome the key stakeholders need to understand both the project proposal and the findings of the feasibility assessment. This understanding forms the basis of informed consent for their involvement if the project were to proceed past the feasibility stage. This understanding is also important in managing expectations in the outcome of the project.

4. **Allowance for limitations on analysis**
   Getting accurate data on all aspects of a project is difficult and, in many cases, impractical. Projections of future events and costs are rarely accurate. Understanding what the limitations of the source data are and how they impact the accuracy of the modelling, and the resulting analysis is important in ensuring the project outcomes are not overstated and stakeholder expectation can be fairly managed.

2.4.3 Assessment criteria

When separately evaluating the three project elements, several assessment criteria can be applied. These assessment criteria should be project specific and aligned with the project aims and objectives. Table 16, Table 17, and Table 18 provide lists of typical assessment criteria for each of these elements. These lists are not exhaustive and may not apply in every case but may provide a minimum basis for many projects.

Table 15: Organizational Assessment Criteria

Organizational	
Assessment Criteria	**Description**
Understanding and approval of all key stakeholders	All key stakeholders have and understanding of the project that is commensurate with their level of involvement and commitment. This understanding includes both the potential risks and benefits of the project and in essence involves an informed consent for their participation.
A sustainable strategy for governance and management of the power system over its full life cycle is in place	An agreed strategy for the governance and management of the power system that will last the full 25-year life cycle has been included in the overall project design. This strategy includes: • All key project roles and responsibilities have been defined, allocated and accepted • Any gaps in the capacity of project participants to fulfil these roles have been identified and structures or processes put in place to address these gaps • Financial arrangements for the management of the power system (loans, grants, tariffs, project incomes and expenditures , etc) are well understood and accepted
Regulatory requirements for the project are well understood and can be met	The regulatory environment for the deployment and management of the power system is well understood and presents no significant barriers that would prevent the project proceeding. Common barriers include but are not limited to: • Land use constraints: existing zoning or similar land use issues • Environmental impacts: protected flora, fauna, cultural heritage , etc • Cost of regulatory compliance is prohibitive (within project budget) • Social or gender equity issues cannot be reconciled
Legal requirements for the project are well understood and can be met	Legal requirements for the project are well understood and key stakeholder are both willing and able to work with these requirements. These requirements include determining (at least in outline) the required legal/contractual structures for the following • System ownership (single, joint, community, commercial, lease , etc.)

	• System financing (loans, grants , etc.) • Land use • Sale of electricity, user service agreements & tariffs • Connection/network agreements (for edge-of-grid systems) • EPC & O&M contracts
Access and tenure for land for the power system is secure	The project requires secure long-term access to suitable land to place the power system and its associated network. Land access has been a major issue for many projects. The proposed site must be • Secure tenure for the power system for its full life cycle is a fundamental project requirement. • Sufficient available space for proposes system: including access to land for any future expansion of the system • Suitable condition: The site must be suitable to house the power system over its whole project life. The site risks (flooding, ground conditions, environment , etc) should therefore be well understood so that they can be avoided or managed • Cost: Invariably there will be a cost for land use which will need to be factored into the overall feasibility.
Project supported by the available supply chains	The existing supply chains must have the technical & financial capacity to deliver the required project services. If gaps in this capacity are identified can they be filled within the framework of the project to ensure supply chains meet project requirements.

Table 16: Technical Assessment Criteria

Technical	
Assessment Criteria	**Description**
Stakeholder and end user technical requirements and expectations	The proposed off-grid or edge-of-grid power system should meet the technical requirements and reasonable expectations of the key stakeholders and end users. These requirements will vary between stakeholder but typically include the following: • System reliability • Quality of supply • System availability • Renewable Energy Fraction (REF) % • GHG emission reductions
Technically Sustainable	The proposed power system is expected to operate effectively for 25-years or more. To achieve this longevity the power system shall meet the following technical requirements • System is designed well and meets

	○ relevant standards ○ existing and projected loads ○ site conditions • System hardware is of reasonable quality, reliable, suited to the site conditions and well supported by suppliers • Installation works are completed to a high standard • Effective O&M is carried out over life of system • Allowance made in design and costing for hardware replacement (i.e. BESS, inverters , etc)
Meet general system design requirements	The proposed power system should comply with the general system design requirements • Reliability • Operating flexibility and efficiency • Redundancy and backup • Renewable energy integration • Design lifetime • Load growth • Operation and Maintenance • Environmental Impact • Protection
Suitability for Site Conditions	The proposed power system should be designed to suit the existing site and make allowance for site conditions including: • Climate/environment • Ground conditions • Site accessibility
Supply Chains	The technical implementation of the proposed system design requires the following elements are in place: • The required system hardware is ○ available ○ supported/warranted by suppliers • There is sufficient industry capacity ○ to supply and install the system ○ to operate and maintain the system

Table 17: Financial Assessment Criteria

Financial	
Assessment Criteria	**Description**
Stakeholder and end user requirements and expectations	The proposed off-grid or edge-of-grid power system should meet the financial requirements and reasonable expectations of the key stakeholders and end users. These requirements will vary between stakeholder and at times may contradict each other but typically include the following: • Minimization of capital and operating cost

	• Project finances are self-sustainable • Effective return on investment for investors • Affordability of electricity for end users • Financial accounting and documentation
Financially Sustainable	The financial sustainability of the project will depend on many factors ranging from the ownership structure, revenue and financing arrangements and aims and objectives of the particular stakeholder. The exact metrics and conditions by which the financial sustainability of the project can be assessed depend on the project itself and must be considered in terms of the proposed 25-year life of the system but include: • Levelised Cost of Energy (LCOE) • Balance of operating income and expenditures • Servicing of debt and equity • Cash flow and cash reserves to meet O&M requirements • Requirements of funding obligations • Allowance for end of life (EOL) remediation if required
Supply Chain Impacts	The strength, sophistication and locality of available supply chains have a direct impact on financial feasibility of a project. In particular the affordability of the project will be impacted by the following interconnected factors: • Overall market competitiveness • Availability of hardware suppliers and ongoing hardware support • Availability of suitable EPC and O&M contractors • System accessibility and distance from markets

2.4.4 Whole of project assessment - summary

As noted, this final stage of the feasibility assessment involves bringing together all the analysis work on the organizational, technical, and financial aspects of the project into a coherent whole and utilizing these findings to inform a whole of project assessment as to whether the project is "feasible" or not. The means to complete this aim are also described in the sections above and include utilizing this proposed assessment structure, following the underlying principles, and applying the various assessment criteria to the specific context of the project. Following this process should ensure that the outcome of the assessment will accurately reflect the feasibility of the proposed project. Section 2.4.1 also describes specific elements of the whole of project assessment, which include:

- Balancing the assessment outcomes for the individual organisational, technical, and financial aspects of the project against the needs of the project as a whole.
- Identifying overall project strengths and benefits.
- Identifying the net project risks and vulnerabilities.
- Nominating potential mitigation requirements for managing identified net risks and vulnerabilities.

The ideal outcome for the project will be that all three project elements, the organizational, the technical and the financial, are each individually determined to be feasible. However often the outcomes of these project assessments are less distinct, not binary, and more nuanced. Also, the failure to achieve this feasibility trifecta across all project elements does not necessarily mean that the project should not proceed. The reasons for this are as follows:

- The determination of what is feasible and what is not, must be made in the context of the aims and objective of the project stakeholders. The assessment metrics may vary from project to project or stakeholder to stakeholder.
- The final assessment for the project requires it to be assessed and balanced across its whole.
- A project or project elements may be determined as unfeasible under current conditions, but if actions or mitigation strategies can be successfully deployed then this status may improve.

A common example that illustrates the importance of context is that for many grants funded projects, the funders are usually aiming for service delivery outcomes for the target community and for a basic financial sustainability for the system rather than a direct financial return on the project funding. So, a project that might be deemed financially unfeasible for an investor led project could be seen as financially feasible by funders with different priorities.

Additionally, there are always strong interdependency between the organisational, the technical and the financial elements. During the assessment process it is important that these interdependencies are well understood, have been allowed for in the modelling and analysis and that the final proposed outcome highlight any contradictory consequences or adverse impacts of the determination of one of these elements on another.

3 Case Study

3.1 Northern Territory, Australia

3.1.1 Background

A remote Indigenous owned and operated cattle station located 10 km from the grid in the NT is currently being powered by a diesel generation system. The Client wishes to conduct a feasibility assessment to decide whether to continue powering the site business as usual, connect to the grid, or upgrade the power system to a PV / BESS / Diesel Hybrid.

If the feasibility study indicates it is beneficial to install a standalone hybrid power station, the Client wishes to know how different system designs (i.e. smaller vs. larger systems) will impact them from an economic, social and environmental perspective.

3.1.2 Geographic context

If the Northern Territory was a country, it would be ranked within the top 20 biggest in the world by land mass. At 1.4 million square kilometres, it is bigger than Peru or South Africa. The United Kingdom could fit into this are five times, with room to spare. Meanwhile, the Territory's population sits at well under 250,000. Most towns of that size are not globally known, and the NT occupies a piece of land the size of Western Europe.

Such a big space and so few people presents significant logistical challenges, and the provision of power is no exception. It is an expensive exercise to traverse this desolate area at the best of times, with wild weather, tricky road conditions and extreme temperatures just some of the additional factors to consider in the delivery of services to remote areas.

3.1.3 Client Goals

Engagement with the Client to better understand their goals for the project resulted in the following key drivers being identified:

1. Maximise financial returns
    a. Maximise net present value and internal rate of return, while minimising payback period
2. Improve power system reliability
    a. Gaining access and delivering essential services (e.g. diesel) to the station can be limited during certain times of the year (e.g. road closures during the wet season) and there is a desire to minimise this risk exposure
3. Minimise operational cost volatility
    a. More stable and predictable long-term cashflows are desired
    b. Current diesel price fluctuations increase operational cost volatility
    c. Currently the diesel price is at a historically low price of ~ $1.20 / L (including delivery) but generally it is between $1.60 - $2.00 / L
4. Improve environmental sustainability
    a. Reduce CO2 emissions
    b. Reduce noise and visual impact on the surroundings

3.1.4 Power Supply Options

Table 19 compares how each of the three realistic power supply options stack up against the Client's identified measures for success (note, some values in Table 19 are speculative and will change depending on the context of application). While it's not an exact science when comparing these power supply options, Table 19 aims to provide a sense check of how these options stack up against each other. Typically the lower the total score, the more suited an option is with respect to a client's goals.

Table 18. Comparison of key drivers for success across different power supply options (1 = most preferred, 3 = least preferred)

Client's measure of success		BAU (diesel only power station)	Grid Connection	Standalone Hybrid Power Station
Financial Return	CAPEX	1	2	3
	OPEX	3	2	1
	Diesel Price Risk	3	1	2
System Reliability	Blackouts	3	2	1
Environmental Sustainability	Carbon Emissions	3	2	1
	Noise	3	1	2
	Visual	1	3	2
	Total	17	13	11

3.1.4.1 Grid Connection

The power station is permitted to connect to the grid as long as the connection is built by the end user and to the utilities standard. The cost to connect to the grid largely depends on the distance and pathway to connection, which is ~10 km, where the pathway is relatively flat and minimal clearing of vegetation is be required. A step down transformer will be required to complete the grid connection, which will be a significant cost. Overhead vs. underground cabling will impact the cost to connect. It seems reasonable at this stage that overhead cabling will suffice from a practical and environmental standpoint. Connecting to the grid will result in a reasonably reliable connection, where it can be expected that several short-lived blackouts may occur during the year.

Operational cost volatility will depend on utility tariff forecasts, which can be relatively stable in the short-term, but can fluctuate substantially in the long-term. The volatility of electricity tariffs will likely be less than the diesel price volatility. With reference to business as usual (diesel generation), the environmental sustainability improves when procuring electricity from the grid. There will be minimal noise from the grid connection power supply option, however the visual impact is the worst rated score across the three options.

3.1.4.2 Standalone hybrid power station

Installing standalone renewable hybrid power stations is commonly and successfully applied in this context. The capital expenditure and operational expenditure will depend on the system components (PV, Wind, Hydro, BESS, Diesel, Gas , etc.) and sizing selected, which will largely be informed through the technical modelling stage that optimises for variables depending on the client's goals. Reliability should improve substantially upon business as usual as there is less reliance on diesel fuel and gaining access to the community and the system can operate standalone.

The volatility of future cash flows will be minimised as this solution is standalone and minimal diesel fuel will be relied upon. Ongoing operational expenditure should also be minimised in this option. Out of all options presented, this solution presents the highest environmental sustainability. Less noise than BAU, however some noise when diesel is generating.

3.1.4.3 Technical Assessment

The technical assessment models the operations of different power stations. This modelling takes into account the load and resource variability across an entire year. The technical modelling ouputs are then run through the financial model to understand how each options stacks up financially. The financial model accounts for the different capital and operational expenditure of each possible technical solution, the capital structure of investment (i.e. debt and equity), and any financial incentives available (i.e. rebates, grants , etc.). The key outputs from the financial modelling stage include the levelised cost of electricity (LCOE), initial investment, net present value (NPV), internal rate of return (IRR), and payback period. These metrics are considered alongside one another within the context of the Client's identified measures for success before recommending a solution.

3.1.4.4 Load Assessment

Electrical consumption (load/demand) data from the Station was not available, however the community provided historical fuel consumption data. The community indicated that there was limited opportunity to reduce load into the future as basic energy efficiency measures have previously been implemented. From the information collected through community engagement, the following was concluded in regard to electricity consumption:

- Typical daily energy consumption ranges between 600 – 800 kWh
- Average daily energy consumption of 672 kWh

Fuel data alone did not suffice to generate a load profile, however considering data from nearby stations that have similar operations and electricity consumption patterns, while also considering the estimated total daily energy consumption, a reasonable annual load profile was determined. The timing and magnitude of peak loads were checked against some of the major operational loads in the community. There is no expected load growth in the community in the short-term. It also appears that all of the energy efficiency measures have been taken already.

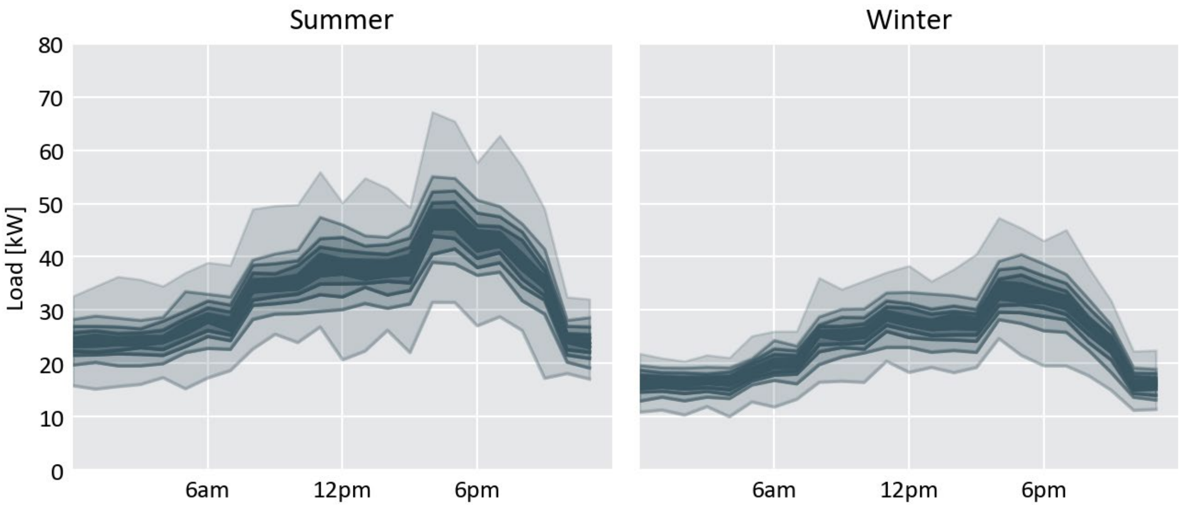

Figure 9. Daily load profile in summer and winter. Each shade of colour represents 20% of the data.

Figure 9 shows the daily summer and winter solar resource profile. The station is located in Northern Australia, relatively close to the equator, and experiences wet and dry seasons. Summer falls within the wet season, which experiences more volatile weather conditions than winter, which falls in the dry season. This volatility in weather is reflected by the load volatility in Figure 9, which will largely result from bigger extremes in cooler to hotter weather. The dry season, while cooler, is more predictable with a large number of clear-sky days.

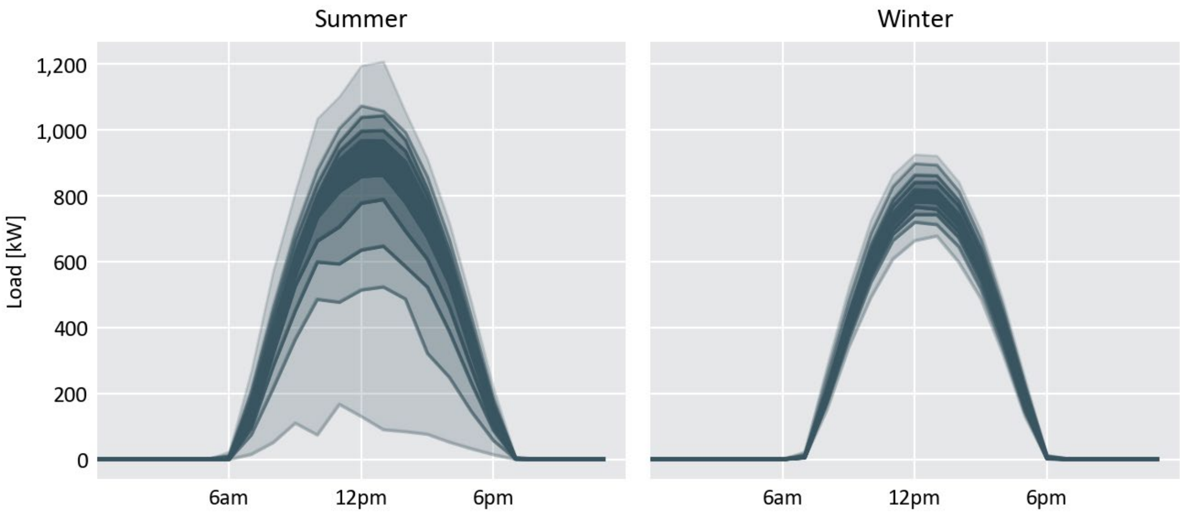

Figure 10. Daily solar resource profile in summer and winter

3.1.4.5 Solar PV and Diesel

The figures below step through scenarios showing the load being served by different sizes and combinations of solar PV, batteries, and changing diesel generator minimum load settings. The figures demonstrate how the same daily load profiles across four consecutive days can be served in a myriad of ways from different technologies when several variables constantly fluctuate and interact. The bottom plots in each figure show how renewable power fractions (RPFs), daily renewable energy fractions (REFs), and where applicable, the battery states of charge (SOC), change throughout and across each day. The figures are a reminder that optimising system design is a challenge when so many fluctuating variables, and different client perspectives, need to be accounted for.

Figure 11 demonstrates how 25 kW of solar PV, without a battery, serves the load across four consecutive days. The diesel generators must operate above 5 kW of minimum loading. Across the four days shown, the 25 kW solar PV array rarely has more power generation available than the load is demanding. As a result, the top plot in Figure 11 shows almost all of the solar PV generation being utilised across each day. On the fourth day at approximately 2pm, a small amount of solar PV is curtailed to ensure the diesel minimum loading stays above 5 kW. The bottom plot in Figure 11 shows that the daily maximum instantaneous RPF ranges from approximately 20% (day 2) to 75%, while the daily REF ranges from approximately 5% (day 2) to 24% (day 4).

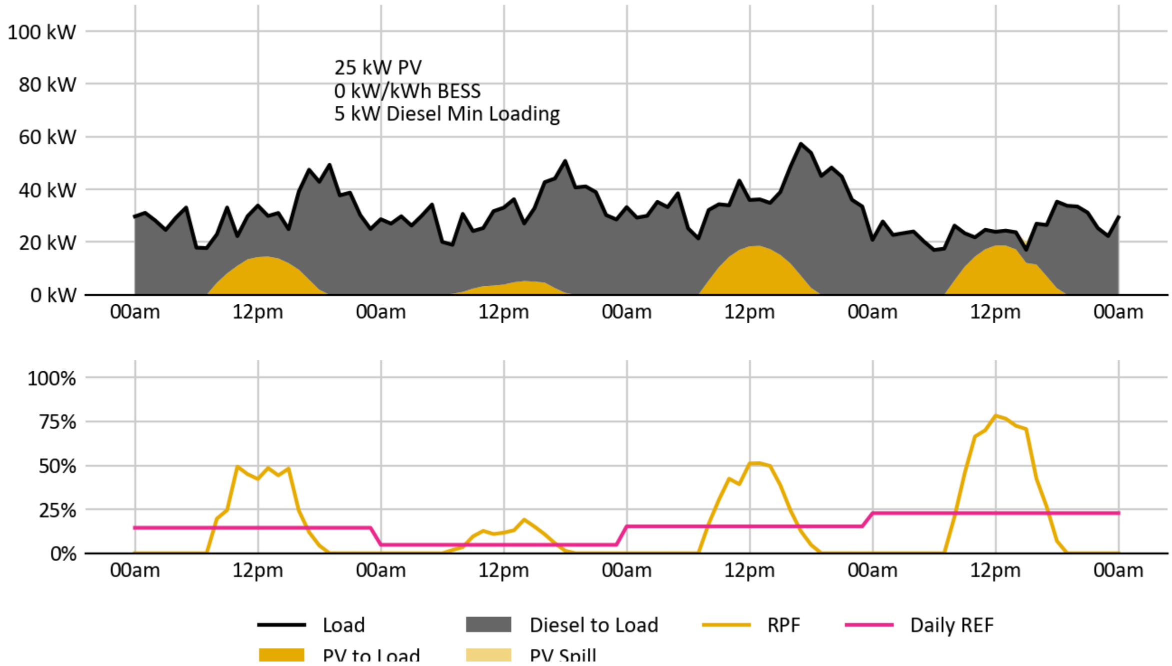

Figure 11. Utilising all of the 25 kW solar PV to serve the load, diesel minimum loading of 5 kW

Figure 12 demonstrates how 100 kW of solar PV, with a 5 kW diesel minimum load setting, serves the load. Compared to a 25 kW solar PV array, there is significantly more solar PV energy spilled (i.e. wasted). A small amount of this spilled energy results from ensuring the diesel minimum load setting is maintained, however the majority of spilled solar energy results from the solar PV energy exceeding the load. With no battery installed to capture this extra available energy, it is wasted. In other words, the much larger initial investment required to install the 100 kW solar PV array, compared to 25 kW, results in offsetting almost no additional diesel generation.

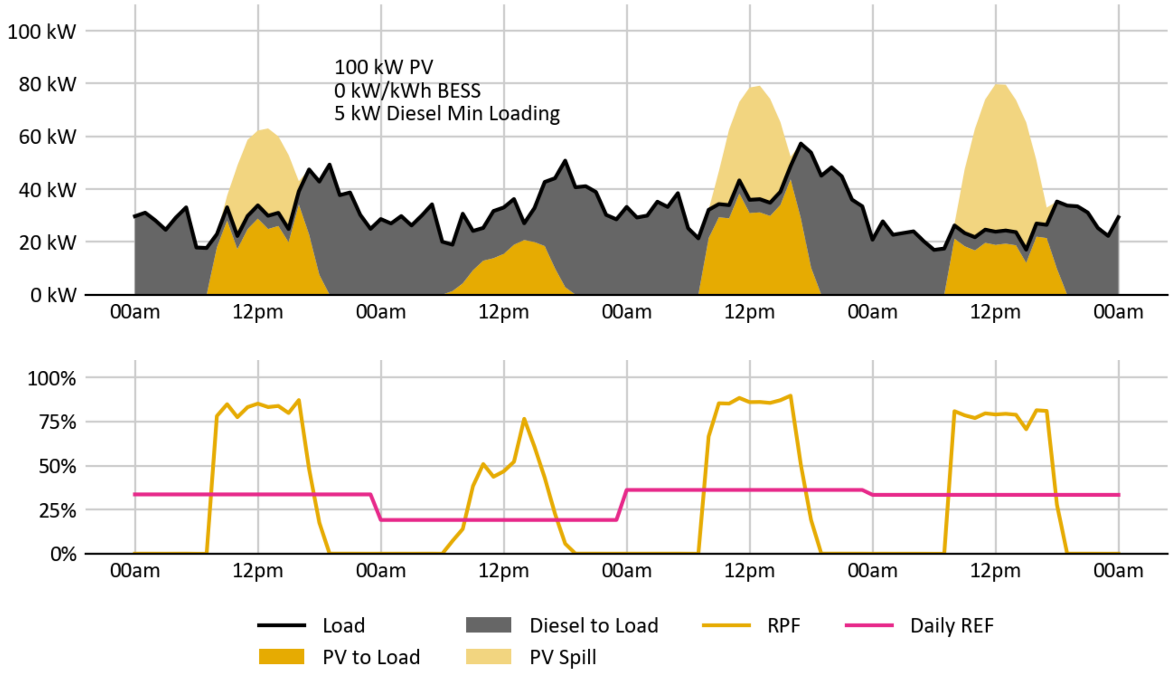

Figure 12. Diesel minimum loading is 5 kW, resulting in some curtailment of the 100 kW solar PV

Low-load diesel generators, which are more commonly being operated, might require loading to sit somewhere between 5% and 30% of nameplate capacity. Within these power supply contexts, low-load diesel generators can result in less curtailment of solar PV generation when compared to more traditional ways of operating diesel generators. The scenario shown in Figure 13 resembles diesel generators requiring a larger minimum loading than that shown in Figure 12. Traditionally, diesel generators can typically require being loaded anywhere between 30% and 60% of nameplate capacity.

Figure 13 shows how this larger minimum loading requirement results in larger curtailment of solar PV generation. The impacts of this additional curtailment are seen by reflecting on the RPF and REF values for the bottom plots in both Figure 12 and Figure 13. RPF and REF values were often reaching 85% and 35% respectively for a 5 kW diesel minimum load setting. However, under a 15 kW diesel minimum load setting, the RPF and REF values dropped to approximately 65% and 25% respectively.

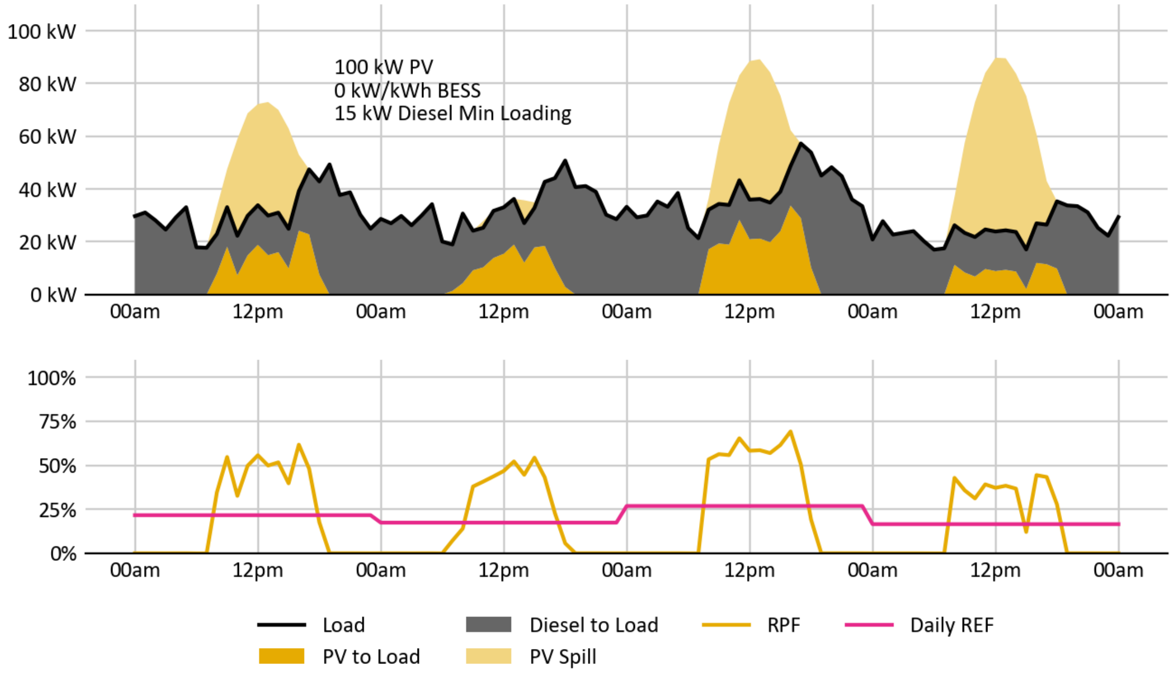

Figure 13. Diesel minimum loading is 15 kW, resulting in significant curtailment of the 100 kW solar PV

3.1.4.6 Solar PV, BESS, and Diesel

Grid-following and grid-forming battery energy storage systems (BESSs) are the two main types of BESSs installed at off-grid hybrid power stations. A grid-following BESS requires the diesel generators to form the grid, meaning the diesel generators must remain switched on. The grid-forming BESS forms the grid and allows for diesel-off operation, thereby enabling 100% RPFs, and in theory, but less likely, 100% daily REFs. Grid-forming BESSs are typically more expensive, however they enable offsetting more diesel.

The sizing of a BESS depends largely on what the intention of it’s use is. Most commonly, a BESS is installed to either smooth variability, or load shift (i.e. offset large amounts of diesel/gas generation). A smoothing BESS is required to charge and discharge large amounts of power at very short time scales. While the power injection support required may be significant, the energy required depends on the length of time that the smoothing event (e.g. cloud occlusion) last for. Often, a smoothing BESS can have larger power ratings than energy ratings for this reason.

A load-shifting BESS is sized appropriately to allow for storing the extra renewable energy available, to then discharge this stored energy later to offset other forms of generation (e.g. diesel, gas). Due to the large amount of energy being stored under this mode of operation, the energy capacity for a load-shifting BESS can be significant.

3.1.4.7 Grid-following BESS

Figure 14 demonstrates the load being met by a 100 kW solar PV array, a 300 kW/ 300 kWh grid-following and load-shifting BESS. The diesel minimum load setting is 15 kW. The BESS state of charge (SOC) is shown on the bottom plot. Figure 14 shows the grid-following BESS requiring the diesel generators to remain switched on throughout the day. The diesel minimum load setting of 15 kW results in curtailing the solar PV. Once the BESS is fully charged (i.e. SOC = 100%), the solar PV spills energy. On days with good solar resource (i.e. day 1, 3 and 4), the maximum RPF and daily REF values hover at approximately 80% and 50% respectively.

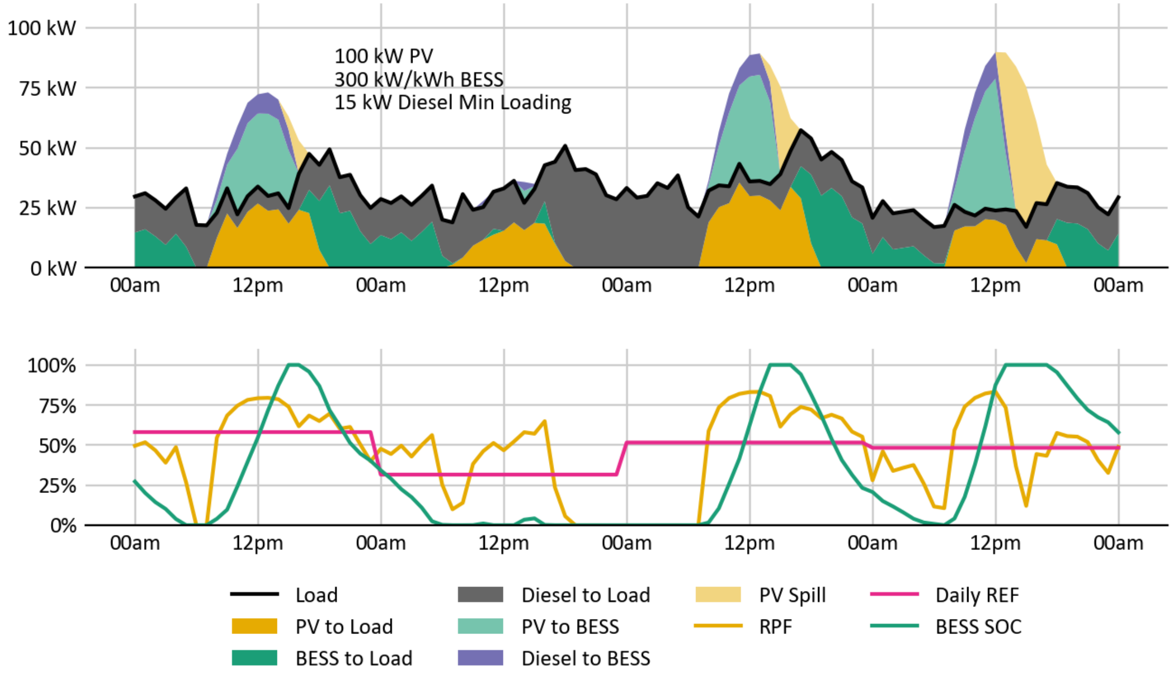

Figure 14. Grid-following BESS requires diesel generators to remain switched on

3.1.4.8 Grid-forming BESS

Figure 15 demonstrates the load being met by a 100 kW solar PV array, a 300 kW/kWh grid-forming and load-shifting BESS. The diesel minimum load setting remains at 25 kW. The main difference shown in Figure 15 is that once the BESS has been charged with enough energy to provide the spinning reserve required (i.e. usually at approximately 10am), the diesel generators can completely switch off as the BESS forms the grid. This results in almost no curtailment of the solar PV throughout the day. On days with good solar resource (i.e. day 1, 3 and 4) the maximum RPF and daily REF values hover at approximately 100% (20% higher than grid-following) and 65% (15% higher than grid-forming).

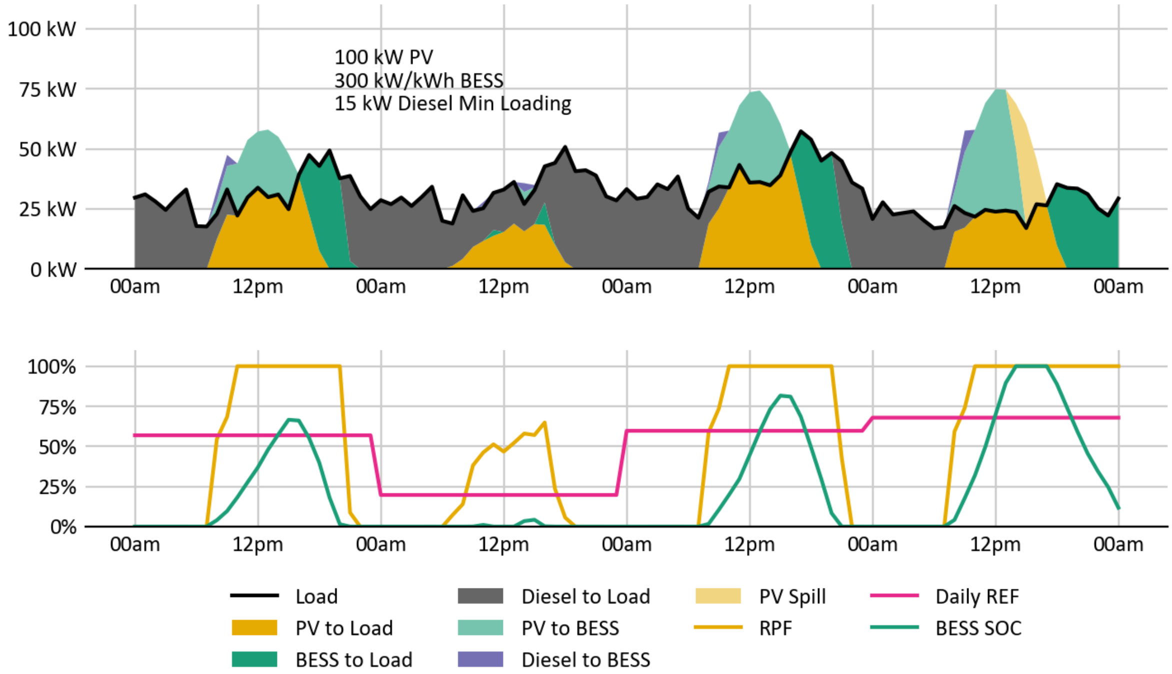

Figure 15. Grid-forming BESS allows for diesel-off operation during the midle of the day

3.1.4.9 Optimising for Renewable Energy Fraction

Given the sites annual load and solar resource profile, Figure 16 demonstrates what levels of annual renewable energy fractions (REFs) can be achieved by installing different sizes of solar PV and BESSs. The BESS is assumed to be grid-forming and load-shifting. A useful way to interpret this figure is to first understand if there is a desired REF to be achieved by the hybrid power station. If so, then Figure 16 can be used to identify what size combinations of solar PV and BESS can achieve this REF. The most financially attractive solution to achieving a REF will ultimatlely depend on the capital expenditure (CAPEX) and operational expenditure (OPEX) for both solar PV and BESS. If the Client has a goal of achieving a minimum REF, Figure 16 is useful way to communicate what system sizes can achieve the desired outcome.

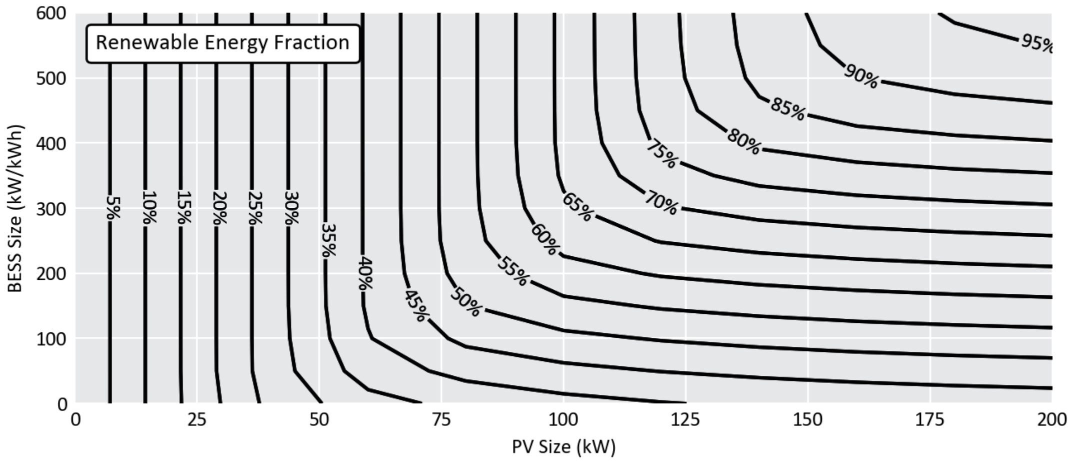

Figure 16. Optimising for renewable energy fraction. The black lines indicate the annual renewable energy fractions achieved by installed a particular solar PV sized array and BESS.

3.1.4.10 Financial Assessment

The financial assessment involves running the technical model outputs through the financial model to determine the financial return for different investments. The following tables highlight the key financial inputs used.

Table 20 outlines the financing costs and capital structure utilised for each investment that is run through the financial model in this case study. These values are not to be applied for all projects and are dependent on the context of the project.

Table 19: Financing costs

Input	Value
Operational Life (years)	25 years
Debt to Value Ratio	100%
Cost of Debt (%)	5%
Cost of Equity (%)	6%
WACC (%)	3.5%
Loan Tenure (years)	7 years
CPI (%)	2.5%
Tax Rate (%)	30%

Table 21 outlines the assumed starting price of diesel. Project experience and extensive research led to a specific price forecast being developed internally and applied in the financial model. All financial returns are highly sensitive to the starting diesel price and forecast, which are volatile variables. Therefore the sensitivity of any expected financial returns should be known before making final investment decisions. Table 21 also provides an assumed green energy certificate price forecast. In Australia, green energy certificates are provided as either

Small-generation unit (STC) or large-generation certificates (LGC) and are priced per MWh of energy.

Table 20: Market prices

Input	Value					
Diesel starting price ($/litre)	$1.38 per litre (with specific diesel price forecast applied)					
Green energy certificate price ($/MWh)	2020	2021	2022	2023	2024	2025+
	$29	$10	$5	$3	$1	$0

Table 22 and Table 23 outline the financial model inupts associated with capital and operations, respectively. These values are not to be applied for all projects and are dependent on the context in which each project is applied. Values are often derived from one or a combination of the following sources:

1. Project experience (e.g. competitive tenders, project delivery)
2. Engagement with people (e.g. local community members, contractors, suppliers , etc.)
3. Reputable reports (e.g. Bloomberg, Lazard, Baringa, Aurora , etc.)
4. Research (e.g. academic papers, journal articles)

In some circumstances, a specific forecast will be attributed to a variable (e.g. LGC price forecast in Table 21 above). When specific price forecasts are unknown or hard to determine, a more simple approach used is to apply a reasonably assumed annual indexation rate. For example, there are many and varied publicly available BESS price forecasts available. Some reports indicate that across the board, BESS prices can be expected to fall by 4% per year, which has been used as the indexation rate to account for the price change when replacing a BESS after 10 years of useful operational life. In Table 22, fixed capital includes control equipment, control room, generation storage and cabling.

Table 21: Financial model inputs related to capital

Input	CAPEX	Index (i.e. Annual price change)
Solar PV ($/W)	$2.20 per Watt	- 4.0%
Inverter ($/W)	$0.15 per Watt	- 4.0%
Grid-forming BESS ($/kWh)	$1,200 per kWh	- 4.5%
Diesel Generator ($/kW)	$600 per kW	+ 2.5%
Fixed Capital ($)	$468,000	NA

Table 22: Financial model inputs related to operations

Input	OPEX
Solar PV ($/$W_{DC}$)	$0.03 per Watt
Inverter Operational Life (years)	15 years

Grid-forming BESS ($/kWh)	**$12 per kWh**
BESS Expected Life (years)	**10 years**
Diesel Generator ($/kW/hour)	**$0.03 per kW per hour**
Maximum Diesel Generator Runtime (hours)	**35,000 hours**

The following figures were generated by running hundreds of scenarios through the technical and financial model across a range of solar PV and BESS size combinations. The figures shows how key financial metrics change depending on the investment made. Many different contexts need accounting for when optimising a solution tailored towards a specific Client. For example, Clients may wish to maximise profit, maximise return on investment, recoup their investment as fast as possible, not invest above a specific ceiling. Different technical solutions will be required to deliver on each of these aforementioned needs. As will be shown, the following contour plots can be overlapped to determine a range of technical solutions available to best suit needs.

Figure 17 shows how the initial investment required changes depending on the size of the solar PV and BESS installed. The relationship is linear since many of the capital costs are assumed on a per unit of nameplate capacity basis. This figure is useful for understanding what system size combinations are possible given certain limits on investing.

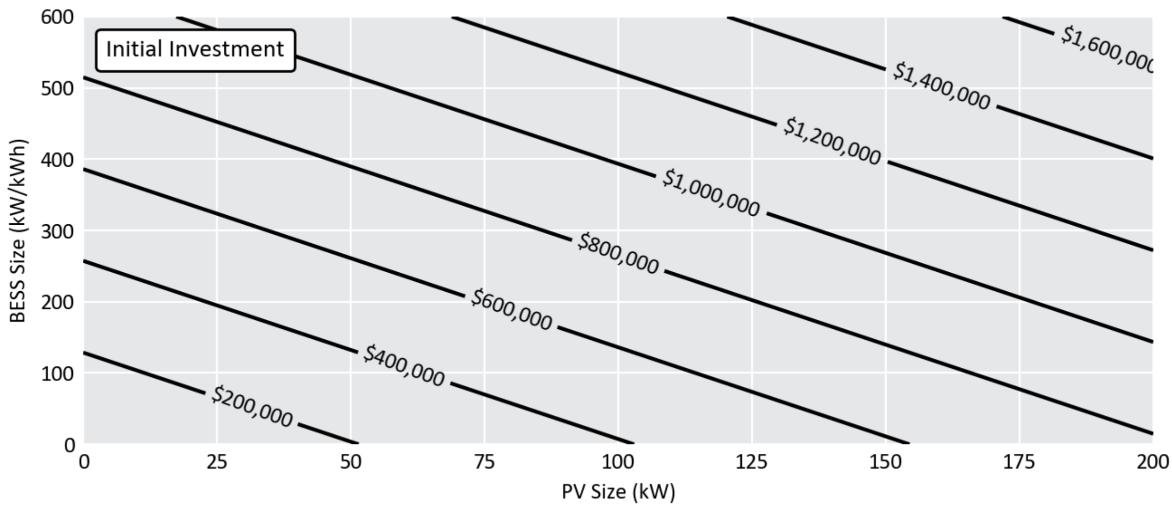

Figure 17. Initial investment for a range of solar PV and BESS size combinations

Figure 18 shows how the net present value (NPV) changes across different technical solutions. The dashed black lines represent negative values, while the solid black lines represent positive values. NPV is often the most considered financial metric when making a final investment decision. Figure 18 shows that an optimal NPV of approximately $700,000 over 25 years can be achieved. The enclosed contours (i.e. circles) identify the range of optimal sizing combinations for solar PV and BESS that are required to achieve this optimal NPV outcome.

For example, if the Client wishes to maximise NPV and minimise initial investment, the Client might consider installing an 80 – 100 kW solar PV array alongside an 80 – 150 kWh grid-forming BESS. This range of options will keep the initial investment down while simultaneously optimising NPV. Alternatively, if the Client wishes to achieve at least an 80% REF, while optimising for NPV, they will need to install at least 130 kW of solar PV with at least 420 kWh of storage. Overlapping the contour plots for each of the Client's goals is a useful way to identify what technical solutions best meet the needs of the Client.

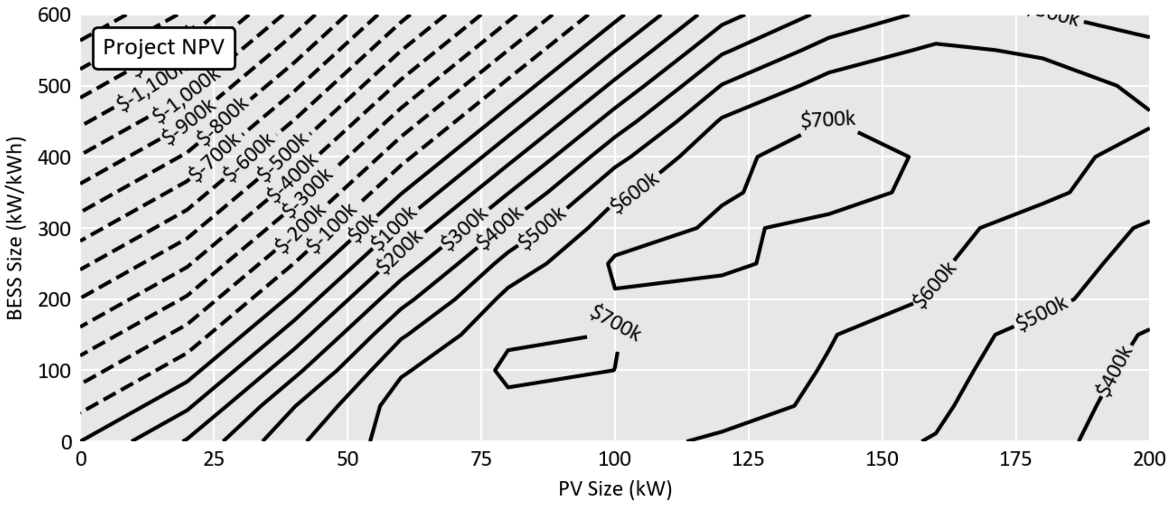

Figure 18. Project net present value for a range of solar PV and BESS size combinations

Figure 19 shows how the internal rate of return (IRR) changes across different technical solutions. Again, the dashed black lines represent negative values, while the solid black lines represent positive values. The IRR indicates the discount rate required for the NPV to be zero. In this case study, the discount rate used on future cash flows is the weighted average cost of capital (WACC), equaling 3.5%. Therefore, any IRR above 3.5% generates a positive NPV. Client investments will often have minimum IRR targets to meet. When an IRR is not high enough, investment will likely flow towards sectors that are capable of delivering high enough IRRs. Figure 19 helps to identify what range of technical solutions allows for the investment to meet IRR targets.

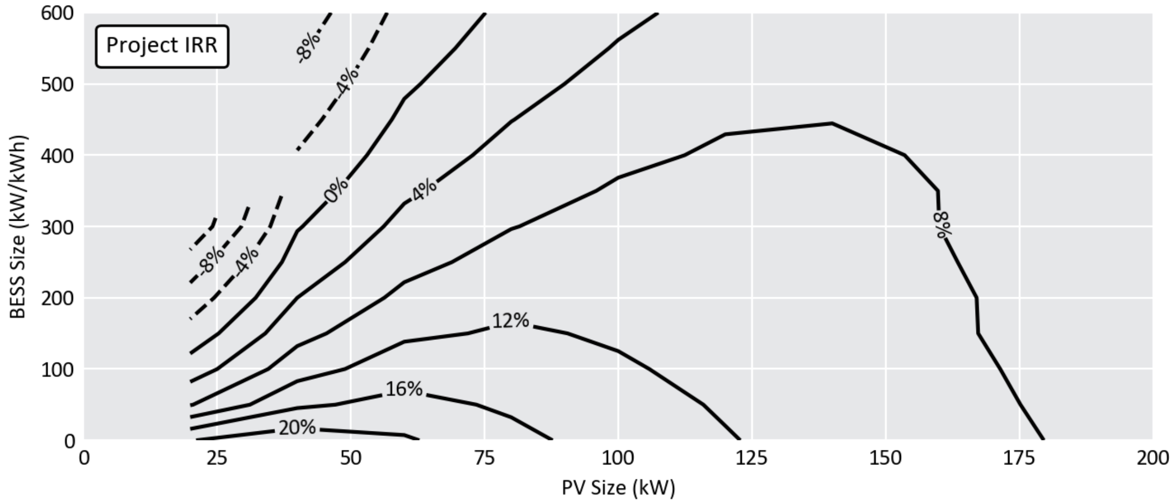

Figure 19. Internal rate of return for a range of solar PV and BESS size combinations

Figure 20 shows how the payback period changes across different technical solutions. The payback period indicates the number of years required to recoup the initial investment. Client's with shorter investment time horizons typcically demand fast payback periods, and vice versa.

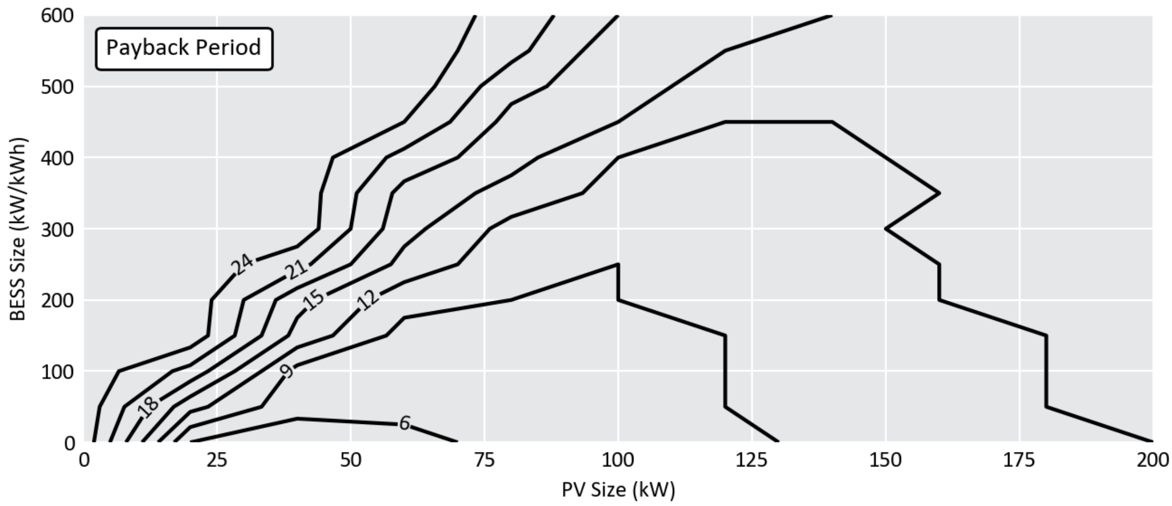

Figure 20. Project payback period for a range of solar PV and BESS size combinations

A common optimisation problem

A common investment goal is to maximise NPV, while ensuring that a minimum IRR target is met. For example, a Client may with to achieve a minimum IRR of 13% for the investment to go ahead. The blue dot in Figure 21 indicates that a 90 kW solar PV array with a 115 kW/kWh BESS will meet this minimum IRR target while, at the same time, maximising NPV.

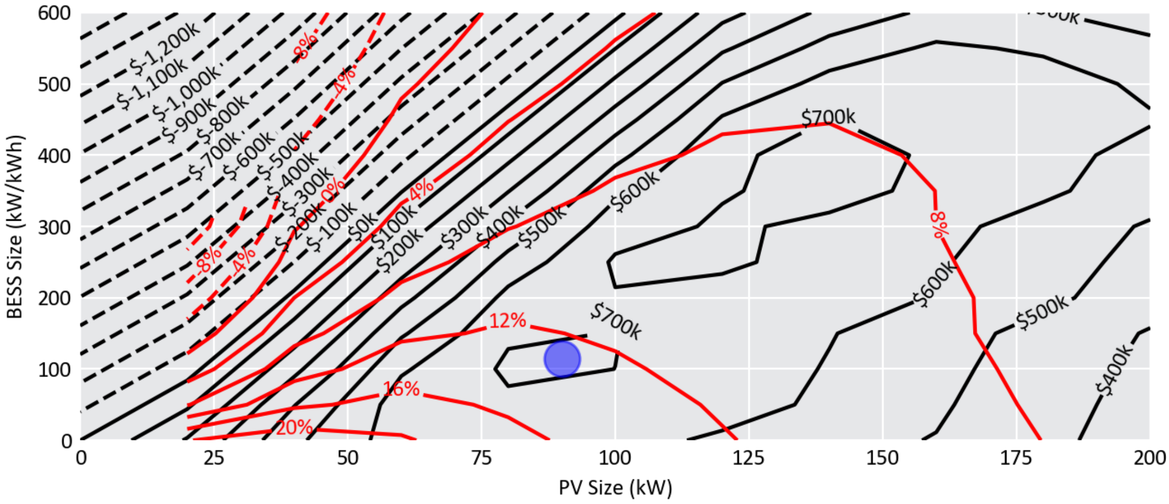

Figure 21. Overlapping the NPV and IRR contour plots. The Blue dot indicates a region that prioritises maximising on NPV, and then IRR.

Optimising for the Client's needs

In this case study, the Client's priority was to significantly reduce their risk exposure to the diesel price, while also maximising NPV. The Client wanted to know what system would deliver an 80% REF while maximising NPV. The blue dot in Figure 22 shows that a 135 kW solar PV system with a 410 kW/kWh grid-forming and load-shifting BESS will meet the Client's needs.

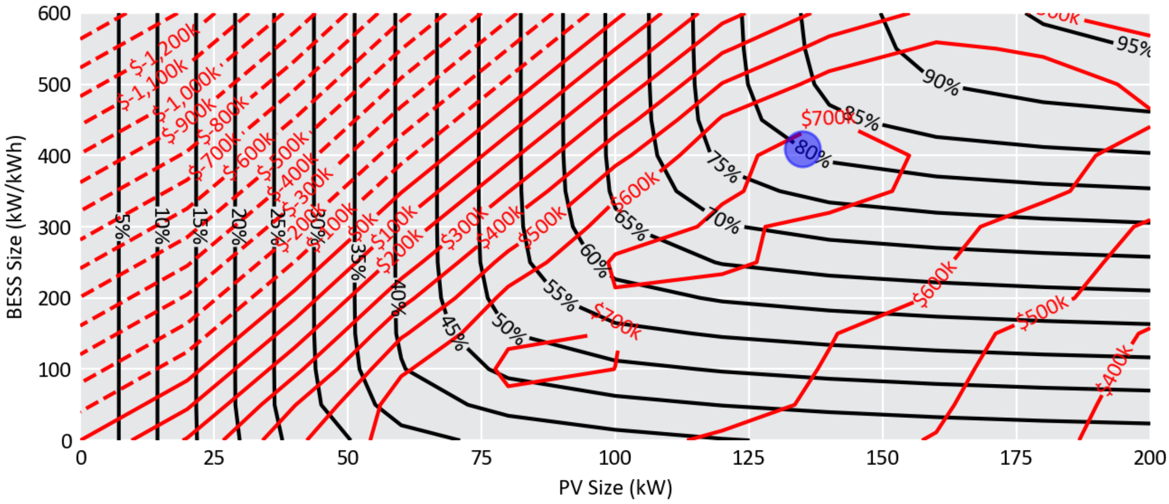

Figure 22. Overlapping the REF and NPV contour plots. The Blue dot indicates a system that delivers an 80% REF, while maximising NPV.

Sensitivity

Figure 23 displays the project NPV's sensitivity against a starting diesel price. The currently assumed starting diesel price is $1.38 per litre. This is based off conversations with the Client where the historical diesel price sits around $1.80 per litre before accounting for the fuel rebate of $0.42 per litre. Hence, $1.38 = $1.80 - $0.42.

Figure 23 demonstrates that a hybrid system achieving a 50% REF is less sensitive to the diesel price changing than a system that achieves an 80% REF. This is because a hybrid power station targeting smaller REFs more closely aligns with the Business As Usual scenario and therefore less of a value proposition exists for systems achieving lower REFs. However, the future operational costs alone for an 80% REF will be less sensitive to diesel price as less fuel will be consumed. Figure 23 shows that for every $0.20 increase in the diesel starting price (i.e. different starting price with the same projected forecast), the project NPV increases by approximately $150,000 and $250,000 for a 50% and 80% REF hybrid system, respectively.

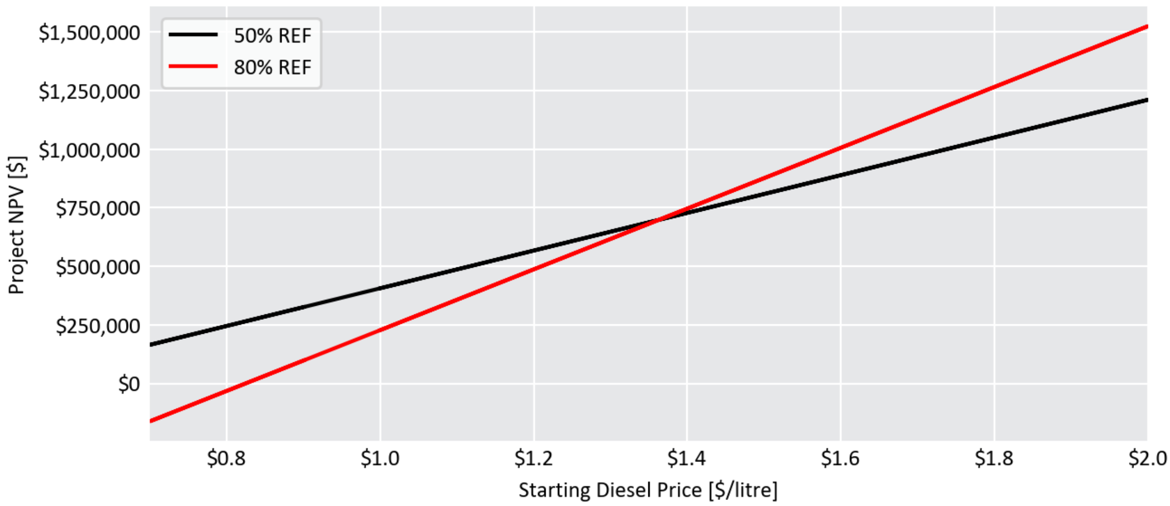

Figure 23. Project NPV sensitivity to the starting diesel price

4 Literature Review

4.1 Executive summary of literature review

As the current covid-19 pandemic threatens the gains in universal access to electricity made in the past decade, estimates show that for the first time since 2013, the population without access to electricity may have increased in 2020 [1]. Distributed renewable energy systems (DES) are agreed by many experts to be the least-cost solution to reverse this trend and put us on track to achieving electricity access for all. As the world emerges from the shadows of covid-19, investments in off-grid / edge-of-grid energy systems are expected to pick back up. A good feasibility study is essential in providing investors, project managers and various stakeholders with requisite information to take informed decision prior to the deployment of a DES. This section of the report summarises various approaches employed in conducting feasibility studies for off-grid and edge-of-the grid renewable energy (hybrid) systems.

A review of literature shows that there is no one-size-fits-all template for conducting a good feasibility study. This is due to different, and in some cases, competing priorities of stakeholders involved in a DES project. Added to this is the layer of complexity due to the combination of more than one technology in DES solutions, which comprise a hybrid system, which are increasingly being favoured in off-grid / edge-of-grid settings. Nonetheless, certain metrics or indicators are found to feature prominently in most feasibility studies. Economic considerations as well as sustainability indicators are observed to be key parameters considered in most feasibility studies.

The reader is presented with an overview of key methodologies utilized in deciding what energy system to deploy, and where, recent trends in financing of DES, and the most common metrics employed in feasibility studies. As with any project, common risks faced by various stakeholders, and suggested mitigation strategies, are given. It is noted that a successful and sustainable implementation of a DES only occurs when identified risks of all stakeholders are correctly mitigated. Since renewable energy resources are distributed unevenly, various technology combinations which could be employed in DES are highlighted. Although no preference is given to any (hybrid) technology, solar system-based technologies appear to be the most studied systems in literature, perhaps given the enormous reduction in solar module prices in recent years, the ubiquitous nature of solar resources and ease of modularity and scalability of solar systems. Lastly, a variety of the most widely used off-grid assessment, optimization and modelling tools are summarized, with key differences / competencies highlighted.

4.2 A brief outlook on energy

By the end of 2019, an estimated 10% of the global population had no access to electricity. Under the United Nations 2030 Agenda for Sustainable Development, Sustainable Development Goals 7 and 13 advocate universal energy while mitigating climate change. Grid extension has been the dominant method in the past decades to electrify whole regions and countries and have been effective in bringing global electrification rates to current levels. However, a combination of factors such as geographical remoteness and low electricity demand, easily makes grid extension very expensive and economically non-viable, leaving large swathes of communities without electricity. Recent developments in technology have led to unprecedented reduction in the cost of renewable energy solutions. This, in addition to advances in digitalization and innovative approaches for energy systems integration, has triggered an energy transition, opening new opportunities for electrification in remote areas, and led to improvement in societal inclusion and human welfare.

In 2019, more than two-thirds of new electricity generation capacity added globally was renewable. Despite the negative impact of COVID-19 on the renewable energy market, global investment in renewable power projects in 2020 exceeded USD 303 billion, with renewables the only source of electricity generation with a net increase in capacity. The positive market sentiment and increasing investments in the sector has led to record low levelized cost of electricity (LCOE) in certain parts of the world [2], [3]. Indeed in 2020, the average global LCOE of solar photovoltaic (PV) and wind power have declined 85% and 56% respectively since 2010, thus making electricity from renewables more cost effective than new fossil-fuel based plants for a greater part of the global population.

In remote and rural areas which are either underserved or unconnected to a national grid, distributed renewable energy systems (DES) are increasingly being employed as viable solutions to the issue of energy poverty. A review of findings by the World Bank in 2007 showed that renewable energy was already more economical than conventional generation for off-grid applications less than 5 kW, and potentially the least-cost solution for mini-grids between 5 kW and 500 kW[4]. Using locally available and free renewable resources, DES can be employed to complement or supplement national-driven electrification efforts. The deployment of DES goes beyond the provision of sustainable energy and environmental protection and leads to general economic development and job creation. In the early stages of the COVID-19 pandemic, some rural communities in Africa and the Amazon benefitted immensely from the DES as essential health facilities were powered through solar PV mini-grid [5], [6]. Thus, underscoring the impact of DES in improving the lives of people in rural areas.

The benefits of DES notwithstanding, in 2020, while investments in renewables in developed countries rose by 13%, it fell by 7% in developing and emerging countries. A recent report showed that the renewable energy policy landscape in high income countries varies vastly from those in low-income countries. While high income countries have very extensive and robust regulatory policies and fiscal incentives for public financing of renewables, the reverse is the case in low-income countries[7].

4.3 Technology/ geography specific off-grid and edge-of-grid feasibility studies

A well-developed body of literature exists on renewable energy and electricity supply in off-grid and edge-of-grid areas. Feasibility studies related to off-grid and edge-of-grid renewable energy systems are usually tailored specifically to the priorities of different stakeholders and address one or a combination of economic, environmental, and system-related issues (technical). A general approach consistent with most literature follows a pattern of technological appropriateness, evaluation of economic analysis and determination of existing incentives [8]. Each of these assessment methods has its strengths and shortcomings. As such, a very effective methodology to assess the suitability of any proposed solution must consider various dimensions such as technical, economic, social/ethical, environmental and institution [9], [10].

A lot of the existing literature on feasibility studies focuses on one or a combination of the following of technical aspects of system design, often with an economic analysis, using a variety of metrics. This is not surprising, given the diversity in renewable energy technologies. This case-study approach is the most common feasibility study method, where the application of a pre-selected technology or a combination of technologies, for a particular location is analysed. This technology-specific and location-specific approach is typically done in areas where an energy resource is perceived to be abundant enough to be considered as potentially viable to meet energy demand.

Although there are variations in how case-study feasibility studies are carried out, a general methodology involves an evaluation of the appropriateness of a technology (or combination of), assessment of economic viability and determination of existing incentives or enablers [8].

To accurately determine the appropriateness of a technology, whether stand-alone or hybrid, a detailed demand and supply assessment is carried out.

Demand assessment involves a detailed analysis of existing electricity demand and potential growth in an area, prior to take-off of the project. The assessment is typically carried out on two levels: community and individual levels and involves surveys and enumeration exercises on-site. The total electricity demand considers the total electricity consumption at each hour of the day, the contribution from different customer groups, average daily load profiles, willingness-to-pay (WTP) and ability-to-pay (ATP) [11]. Data from demand assessment is used in forecasting effective demand, and takes into account future population growth, increase in economic productivities and changes in consumption patterns [12].

Supply assessment entails estimating the renewable energy resources suitable to the pre-selected technology. Where existing information such as satellite data is available, it is used as a baseline for supply assessment for a first approximation. However, this is usually followed up with actual ground measurements or more accurate determinations of resources in the specific areas of planned deployment. The next step utilizes data from demand and supply analysis for system sizing, to evaluate the appropriateness of the technology and ability to meet current and expected demand. Several modelling tools have been developed to help in the optimization of system sizing due to the large number of input parameters used for sensitivity analysis. In addition to design optimization, several modelling tools are widely used for economic and multi-objective optimization. A summary of the most used tools is presented in Table 3.

The **cost of electricity supply** and the economic viability is analysed using modelling tools, and takes various inputs obtained from survey analysis, renewable resource data and relevant financial data. The Levelized-cost-of-electricity (LCOE) is a common parameter to measure the cost-effectiveness of hybrid systems in case-studies and is compared to current energy cost in the area as a way of determining the economic viability of a technology. Other key financial metrics used in feasibility studies are summarised in section 1.1.6.

The **regulatory and institutional environment** influences the potential for growth and the feasibility of renewable energy projects, as such, is a common consideration in case-studies. Optimization of tariff structure and the cost-effectiveness of a pre-selected technology in any location depends on the institutional and regulatory environment. Off-grid developers like to know what incentives, if any, are available in the region, as well as disincentives that could make an otherwise good business case for a cost-effective technology, risky.

4.4 Categorisation methodologies for off-grid feasibility studies

In some instances, investors or aid organizations interested in deploying DES do not favour a particular technology or location over another. Thus, the technology/geography-specific feasibility study method becomes insufficient to determine the suitability of any technology, necessitating the need for the introduction of more complex indices and optimization techniques in decision making.

Some important categorisation of methodologies for analysing off-grid electricity supply were presented by Bhattacharyya et.al [8]. The most common ones are the indicator-based approach, optimisation techniques and the multi-criteria decision-based approaches.

4.4.1 Indicator-based approach

The indicator-based approach is a decision-making methodology which uses one or various sets of indicators, such as financial indicators, grid generator score indicators, ranking or weighted score system and sustainability indicators. A comprehensive list of indicators from various organisations can be found in literature [13]–[15]. Most indicators are however very general in design and can find greater use in policy formulation or strategy on a national level[16]. Here, we highlight three (3) major indicators: levelized cost of energy (financial indicator), weighted score and sustainability indicators [8].

4.4.1.1 LCOE

The levelized cost of energy is a common appraisal method used to compare the cost of electricity generation between different technologies. It covers the cost of capital, fixed and variable operation and maintenance, fuel costs and plant decommissioning. This indicator has been widely used in determining the cost-effectiveness of one technology compared to another and can be used on a wide range of generation capacities [17]–[20]. This indicator can be used to identify potential areas for decentralized electricity from the grid or renewable supply, and for different geographical terrains [21]. Due to the importance of input parameters in LCOE calculations, LCOE would vary broadly for a given technology across different locations or countries. As a result, using LCOE estimates obtained in a particular location and generalizing for a different place could be widely misleading. However, for locations where input parameters can be collectively grouped within a reasonable range, LCOE can provide a quick insight to the cost-effectiveness of given technologies.

4.4.1.2 Weighted Score

The weighted score system considers various aspects relevant to a proposed distributed generation option, such as technical, government regulations, environmental and social aspects [22]. A set of indicators relevant to each aspect is identified and a score allocated based on the importance of the indicators. The total scores are then weighed and used as a basis for a ranking system, useful for decision making. This approach has been used to solve micro-grid location issues by segregating an area into a no-generation or independent generation site, where the no-generation site will be ideal for micro-grid connection, and the independent generation site as a generation point [23]. The weighted score can be a very useful decision-making tool to help investors decide which countries to focus off-grid investments in, by considering market potential, political and financial environments [24]. Differences abound from study to study on what aspects are to be considered, frameworks against which weights are to be given and stakeholders involved in the scoring process [25]. The inherent subjectivity in choosing indicators and deciding weight allocation criteria, makes standardisation of this method impossible. However, that could also be seen as advantageous since it gives decision makers the flexibility to decide what parameters are most important to them. While it may be a useful tool for first-choice decision making, a detailed analysis is always required prior to project commencement.

4.4.1.3 Sustainability indicators

Increasingly, sustainability indicators are being used as a criterion to measure the success or failure of off-grid renewable energy systems, in the broader context of sustainable development. Some useful sustainability indicators designed and selected through an iterative process, and assessed based on field experiences was developed by Ilskog et al[9], [10]. These indicators are based on five dimensions of sustainability, similar to that developed by the UN commission on sustainable development [26]: Technical, Economic, Social/ ethical, Environmental and institutional sustainability. Like the weighted score indicators, the selected indicators are assigned a score and ranked. Although originally applied to installed off-grid systems as a way of benchmarking their overall contribution to sustainable development [10], [27], results from analysis using this method could be very useful in helping decision makers in feasibility studies.

Optimisation techniques

To deliver the least-cost electricity solution to end-users, most off-grid system solutions are a hybrid, composed of one or more energy conversion technologies. This is unsurprising given the intermittency in many renewable energy sources. Energy demand from end-users does not also remain constant throughout the day, necessitating the need for a balance between energy supply and demand. Computer programs, ranging from simple linear programming models to more complex, multi-dimensional programs have been developed to manage the complex interaction between different technologies, energy availability and demand, and other technical and even social constraints. Optimisation models are also useful in maximising certain desired parameters, for example net revenues, and can have non-energy related constraints which are useful within the framework of sustainable development [28]. Optimisation tools are very sensitive to initial inputs and conditions and can lead to inaccurate or skewed results, depending on the (in)accuracy of conditions provided. Additionally, they mostly tend to focus on techno-economic dimensions and ignore the increasing dimensions of social-political and ethical considerations. A summary of various useful optimisation software is presented in Table 3.

Multi-criteria decision analysis (MCDA)

The complex interactions between different dimensions of sustainability, makes sustainable energy decision making difficult. Often, the multi-dimensional nature of a project or policy, features competing objectives, high uncertainties, different forms of data and multiple interests [29]. Multi-criteria decision analysis (MCDA), which is a generic term for all methods that help people make decisions according to their preferences, provides a method to eliminate difficulty in decision involving interactions of criteria across different levels. MCDA, rather than assuming a single decision criterion, assumes multiple criteria are important in the decision-making process. As a result, MCDA methods are helpful to identify complex policy and planning methods, as well as trade-offs and compromises. The most common MCDA method is the analytical hierarchy process [30], which essentially involves breaking a complex problem into a hierarchy, with the over-arching objective at the top, judging criterions at levels and decision alternatives at the bottom. This method is widely used in sustainable energy decision making, analysed across different sustainability dimensions, with investment cost and CO_2 emissions weighing heavily above other evaluation criteria [29].

Energy Sector Management Assistance Program (ESMAP) guidelines

The joint UNDP/ World Bank Energy Sector Management Assistance Program (ESMAP) provides a step-by-step approach for project managers implementing a decentralized energy (DE) project [31]. The guidelines presented are generic and cover activities of decentralised energy systems (DES), hence, is applicable to off-grid and edge-of-gird electrification solutions. Although the guidelines do not consider social and environmental conditions, when combined with these missing indicators, will present an over-arching summary of best practice for off-grid feasibility studies. These guidelines have been widely adopted by project managers and form the basis for a lot of off-grid/ mini-grid feasibility studies.

Assessment of institutional & regulatory environment

- Identify agency or relevant institution responsible for DE, and measure national/ local government support for DE
- Determine whether electricity law allows for provision of DE by private entities
- Identify existing market barriers e.g., laws, tax regimes, subsidies and policies which may unfairly increase cost of DE
- Identify and assess local technical capacity
- Identify and assess local financial institutions
- Identify and assess private sector interest

Market assessment & identification of project concept

- Extensive market studies
- Collate existing information on geographic boundaries, socio-economic factors (e.g., ability and willingness to pay, income seasonality), market niche, population density, buying characteristics
- Analyse competing products and services
- Identify cost of energy services and disposable income of potential customers

Technology and product options

- Identify available energy resources in the area
- Identify available technologies in use in the area
- Energy demand estimation in terms of form, use and quantity
- Determine most appropriate technology option
- Select product delivery option
- Product testing and specification preparation

Delivery mechanism

- Assess the availability of credit in the area
- Assessment of local distribution infrastructure
- Determine the affordability of DE technology relative to current cost of energy services in the area
- Selection of product and delivery channel e.g., cash/ credit/ product lease or provision of energy services
- Establishment of efficient distribution system

Evaluation of financing options

- Assess/ identify financing needs
- Evaluation of rural banking system and the availability and cost of credit
- Identify local partners
- Identify financing options and programs
- Determine financing terms

4.4.2 Financing

The most vulnerable people who will benefit the most from off-grid energy solutions, live in rural areas and are generally poor. Poor households spend about 60% of their income on food [32], hence have less disposable income to meet their other needs. The economic fallout of the Covid-19 pandemic has only made a bad situation worse. As a result, upfront cost remains a major restriction to achieving universal clean energy access. Yet, to reach electricity targets by 2030, over US$ 35 billion per year in total investments is needed to achieve universal access. Private and public finance for energy access is often directed to on-grid or large-scale energy projects due to their financial viability. This investment gap has historically left decentralised energy markets at the mercies of mostly bilateral and multilateral sources for financing. Off-grid solutions for instance benefitted a meagre 1% from over USD 30 billion committed for expanding energy access in 2015-16 [33]. The bilateral sources are mostly OECD countries, which provide finance through grants, concessional loans, and investment guarantees. Multilateral sources, most notably the World Bank and other regional development banks (e.g. Asian Development Bank and African Development Bank), provide finance through grants, credits and risk guarantees [34].

Decentralised and low-income energy markets, which have tended to be ignored by private and public finance due to their high-risk, long-term nature, are beginning to show growth among impact investors, driven by Angel investors [35]. Innovation in pay-as-you-go systems coupled with real-time monitoring systems, have led to significant reduction in investment risk. In addition, a wider availability of consumer finance, rising incomes and expansion of infrastructure and rural connectivity, are increasing the global appeal for off-grid/ mini grid solutions [36]. As a result, there's an increase in PAYG systems being sold, with great success stories especially in East African countries where the M-PESA mobile payment technology

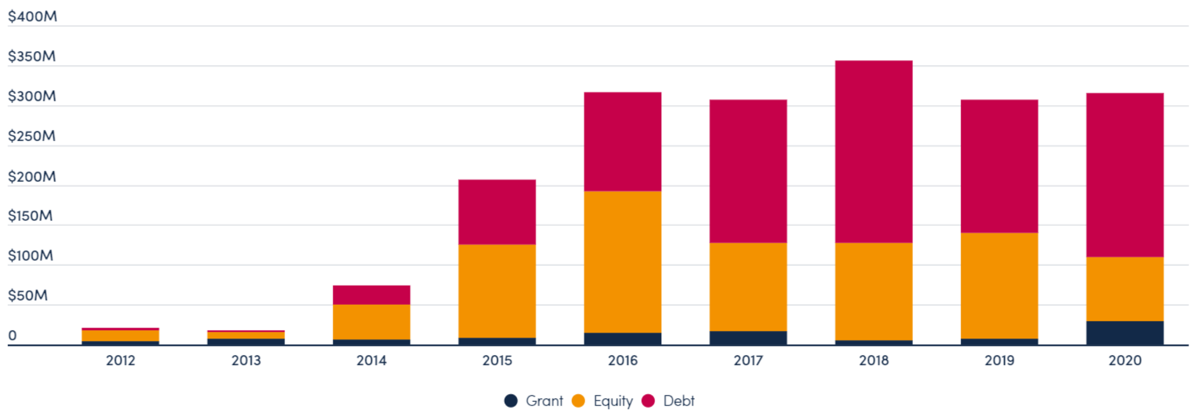

Figure 24: Global financing blend in the off-grid solar sector

was developed [37]. Globally, between 2011 and 2016, there was a six-fold increase in the number of people benefitting from off-grid solutions, with more than 133 million people reached [38]. Sub-Saharan Africa which accounts for 75% of people without electricity access in the world, requires about USD 135 billion in cumulative investments to achieve energy access by 2030. Mini-grid and off-grid solutions have been identified as the least-cost solution for more than 60% of the population. Figure 1 shows the investment in solar sector categorized by sources of finance. Investment data from Global off-grid Lighting Association's (GOGLA) Deal Investment Database, shows that SSA has consistently gained the lion's share of investment, with 67% deals going to the subregion in 2020 [39], [40].

In 2020, global debt financing for off-grid projects increased by 19% while equity financing fell by a massive 46%, compared to 2019. This was probably due to perceived risks in target markets. Debts are provided mostly by multilateral institutions and impact investors, with crowdfunding contributing 10% in the sector. The level of investments from crowdfunding, highlights its consolidation as a debt finance mechanism. Although the absolute cumulative value of grants awarded in 2020 was lower than the previous year, the volume of grants hit an all-time high [40]. Grants are crucial to finance new market players with innovative business models and products and funds many early-stage companies, and usually come from multilateral institutions. In a recent survey among investors in off-grid/ mini grid sector, over 75% thought their investments were in line with their financial and impact expectations. In the same survey, investors were generally optimistic about the stage of the market, with 80% considering that it is growing steadily, mature or about to take off [40]. This indicates good investor confidence both in off-grid investments and prospects for the future. In countries or regions perceived to be risky or with poor underlying economics, concessional financing, such as the Covid-19 off-grid recovery platform launched by the AfDB, will continue to be critical in driving investments in the sector by unlocking private capital [41]. To encourage private partnership in clean energy financing, some new initiatives which provides platforms to connect different stakeholders to the private sector, have emerged, such as the Climate Investment Platform by the International Renewable Energy Agency (IRENA) and get-invest.eu, which is supported by the European Union.

4.4.3 Key metrics used in feasibility studies

Availability of energy resources: This involves the access to diesel fuel, cost of diesel fuel, and the available renewable energy resource in the targeted area. The renewable energy resource and data on solar radiation, wind speed, temperature, biomass, and biogas. The feasibility of a project will depend on the availability of these energy resources.

Net present cost (NPC): This represents the present value of all the costs the system incurs over its lifetime, less the present value of all the revenue it earns. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and sales to an external grid (but does not include sales from the load it is serving). A lower net present cost will redound to lower pass-on rates to end users. For a project to be considered feasible, the NPC must be positive.

Levelized cost of electricity (LCOE): The levelized cost of supply is a common indicator used for comparing cost of electricity supply options. LCOE takes care of the capital expenditure (CAPEX), operating expenditure (OPEX), fuel costs, project financing , etc. It is an average cost per kWh of useful electrical energy produced by the system. To calculate the LCOE, the equation below can be used:

$$\mathrm{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electrical energy production over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where I_t denotes the capital expenditure in year t, M_t represents the O&M expenditure in year t, Ft is the fuel expenditure in year t, Et denotes the electrical expenditures in year t, r is the discount rate, and n is the lifetime of the project

GHG emissions: This calculates the system emissions (in kg/year). The emissions include levels of carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulphur dioxide, and nitrogen oxides. This parameter may be used to measure environmental impact when compared to business-as-usual systems. The effect of GHG emissions has no effect on investment decisions by a potential private sector investor. GHG emissions doesn't trigger concrete cash flows and it is unlikely that the existing carbon market mechanism result in sufficient cash flows. Only the public and government consider external factors like GHG emissions in assessing the economic viability of a project.

Internal Rate of Return (IRR): This is the discount rate at which the net present value of the cash flow of a project is zero. The IRR may be calculated based on either economic or financial (determined by the market) prices of all costs and revenues (or benefits). If the financial IRR is less than the cost of capital, it implies that the project would lose money. If the economic IRR is less than the opportunity cost of capital (predetermined cut-off rate of investment), the project is not viable from an economic point of view.

Payback period: This is the length of time needed to recover initial investment or break even on a project. It may be determined using either discounted cash flow or non-discounted cash flow. It is calculated by dividing the amount invested by the annual net cash inflow. The shorter the payback period, the greater the feasibility of such projects.

Weighted Average Cost of Capital (WACC): The WACC is the average rate of return that an organization is expected to compensate its various providers of capital - whether equity holders or lenders, with each category being proportionately weighted. In other words, it is the minimum revenue a project must generate to keep and give a return to its finance providers or investors. WACC is used in financial modelling as the discount rate to calculate the net present value of a project and it is based on the proportion of equity, debt, and preferred stock. A higher WACC tends to put investment activity under strain.

4.4.4 Risks/ mitigation

There are four key stakeholders in the off-grid/ mini-grid sector: consumers, suppliers, financiers, and policy makers. Successful implementation of sustainable energy strategies or technology in any locale will require adequately addressing the challenges and risks facing all four stakeholder categories. Table 2 presents a summary of key risks faced by various off-grid stakeholders and suggested mitigation strategies.

Table 23: Risks faced by various stakeholders in an off-grid/ edge-of-grid DES: IEA: financing clean energy transitions in emerging and developing economies 2021

Risks	Mini-grids/ off-grids/ edge-of-grid	Mitigation strategies
Revenue risk		
Electricity demand	Lower-than expected electricity demand or defection by grid-connected customers	Improved demand assessment and access to credit; integrated offerings including appliances and end-use equipment
Energy resource supply	Over-estimation of energy resource availability; under-estimation of future electricity needs of customers	Improved supply estimation using state-of-the-art optimization/simulation tools;
Affordability	High price per connection; customers with low and unpredictable income; high cost of equipment	Reduced upfront costs with longer repayment methods; improved access to credit; initiatives to reduce taxes and tariffs on equipment; promotion of commercial use of energy; establish collaboration with training institutes for technology transfer/ skills acquisition
Technology	Sub-standard performance; scarcity of spare parts; lack of technological know-how	Established public policy to improve standardization; supplier buy-back or maintenance guarantees
Tariff level and subsidies	Uncertainty over subsidies, lack of local adjustments; too high tariffs	Viability gap financing from public sources; integrated service contracts
Financial risk		
Working capital	Shipping delays between point of sale and destination	Financing instruments to address working capital needs
Financing needs	Mismatch between expectation and returns	Enhanced support from an ecosystem of investors to offer adequate financial sources
Currency risk	Difficulties raising capital in local currency	
Political risk		
Security	Theft or vandalization of equipment	Strong community involvement;

Default risk	Contract defaults between government entities and investors; expropriation of private property	Improved participation of DFIs in provision of partial loan guarantees.
Regulatory risk		
Registration and licensing	Unclear licensing rules; barriers to developers offering other services; delays in permit approvals	Improved dialogue among government entities; legal and regulatory protections and visibility over grid encroachment by utilities, learning from successful models; clear policy statements and targets
Tariff setting	Inadequate tariff-setting methodology	
Interaction with grid	Unclear regulations for grid encroachment	

4.4.5 Different hybrid technologies

There are various technologies included in hybrid power stations around the world. Some of these technologies are highlighted below:

a) **Small Hydro/Diesel**: Hybrid small hydro/diesel is a low-cost solution compared to many other hybrid combinations. The operational cost of hydropower plants is low. However, hydro is highly site-specific.
b) **Solar PV/Diesel**: Hybrid solar PV/diesel mini-grids are cheaper than diesel-only mini-grids. However, this combination entails a high capital cost of solar PV and ongoing diesel fuel costs, and a high maintenance cost for diesel generator.
c) **Wind/Diesel**: Wind power technology is site-specific. Operational costs of wind are high, which makes hybrid wind/diesel less cost-effective compared to hybrid hydro/diesel. However, this combination is cheaper than diesel mini grids, which is highly dependent o fuel price.
d) **Solar PV/Wind/Diesel**: Hybrid combinations with diesel generators as a backup are the common solutions and economically viable compared to 100% renewable combinations.
e) **Solar PV/Wind/Biogas**: Hybrid solar/wind systems with biogas as a backup seems to be more cost-effective than using diesel as a backup because biogas can be produced locally by feeding a digester system with manure which can be obtained year-round in most locations.
f) **Solar PV/Wind/Battery**: 100% renewable energy hybrid combinations are currently economically less attractive (higher LCOE) than hybrid renewables/diesel combinations that can rely on diesel generators when one of the intermittent renewable resources is not available. This is mostly due to current high cost of batteries per kWh, which is however on a steady decline due to mass production and increased adoption of electric vehicles (EVs).
g) **Wind/Solar PV/Diesel/Battery**: Hybrid wind/solar PV/diesel/battery can be less economically attractive than the hybrid systems, which include hydro. Solar PV highly affects the LCOE because their technologies have high capital costs at low conversion efficiencies [43], [44].
h) **Solar PV/Diesel/Wind/Battery**: This configuration is attractive in areas with a reduced solar potential.
i) **Wind/Hydro/Diesel**
j) **Hydro/Solar PV/Wind/Diesel/Battery**: although more complicated and requires high technical expertise, this configuration can be an efficient hybrid configuration in terms of cost savings and GHG emissions.
k) **Solar PV/Biomass/Battery**: Biomass is an abundant source of energy around the world, which is composed of organic matter, and is assessable throughout the year in most places. In addition to solar PV and battery, is a good hybrid solution in remote areas.
l) **Hydrogen fuel/ other RE combinations:** using an electrolyser, any combination of RE systems can be used to split water, biomass, or fossils such as natural gas, into hydrogen. The higher energy density of hydrogen, compared to lithium-ion batteries for instance, and their longer lifespan, makes this configuration a very promising off-grid energy technology of the future.

4.4.6 Off-grid planning tools

A variety of tools exist to assist an off-grid system developer in decision making. Due to the versatility of a project implementation cycle and the various renewable resources available, there is hardly a one-size-fits-all toolkit, rather project planners use a combination of tools. In tables 3 and 4, a summary of some of the most used tools are presented. The tools shown in Table 3 are mostly employed in preliminary research stage of site selection. Mapping tools, often based on GIS mapping techniques can be used to generate interactive maps and can contain high-level information. Information such as areas not connected to the grid, areas with planned grid extension, population density per location, and socio-economic data can be easily visualized. Tools for resource assessment provide information regarding a renewable energy resource, with some tools able to show comparisons between different energy resources. Data collection tools are useful in site surveys to capture accurate information, which in addition to other high-level information obtained from mapping tools, are useful in decision making. They range from generic everyday tools such as Microsoft office suite to RE specific project development tools such as *Odyssey*, which can also give high-level analysis of the findings of a field survey [45].

Table 24: Off-grid assessment tools [46]

Off-grid market assessment/ Mapping tool	Renewable Resource assessment Tool	Resource	**Data collection Tool**
ArcGIS	SOLARGIS	Solar	KoBo Toolbox
GeoSim	SWERA	Solar, wind	Odyssey
SWARM, Powerhive	Global Solar Atlas	Solar	Quick Tap Survey
DevelopmentMaps	Global Wind Atlas	Wind	Google forms
ECOWREX WRI	POWER	Climate, wind & solar	Microsoft office suite
Google Maps Bing Maps OpenStreetMap	RE Explorer	Biomass, geothermal, hydro, solar, wave, wind	

While energy demand in off-grid areas is low, demand growth is even often slower, compared to urban areas. Because most off-grid dwellers have low and often unpredictable income, any solution that will provide sustainable electricity must be cost-effective. To achieve this, it is typical to combine more than one system to provide the least cost-option to consumers. Thus, many electricity solutions in off-grid areas are hybrid in nature, which makes cost and operation assessment more complex and challenging.

To address this, several mathematical based modelling tools have been built to both cost and performance assessments.

The models can be categorized as simulation, equilibrium, top–down, bottom–up, operation optimization, or investment optimization models (Connolly et al. 2010). A simulation model simulates the operation of a given energy system to supply a given set of energy demands and is operated in some time steps over a year. An operation optimization model is a simulation tool that optimizes the operation of a given system. An investment optimization model is a scenario tool that optimizes the investments in new energy resources and technologies (Connolly et al. 2010). Some models combine some of these features.

Table 25: various modelling and optimization tools

Model	Description	Simulation	Operation Optimization	Investment Optimization
AIM/End-use	Cost minimization modelling tool for energy planning		✓	✓
ASIM	Simulates solar/diesel power system operations and conducts analysis of its technical and financial performance, ideal for system design	✓		
FINPLAN (Financial Analysis of Electric Sector Expansion Plans)	Assesses the financial viability of projects, considering financial sources			✓
GEOSIM	Determines the most cost-effective electricity generation options			✓
HOMER (Hybrid Optimization of Multiple Energy Resources)	Handles grid and off-grid systems	✓	✓	✓
LEAP (Long Range Energy Alternatives Planning)	Modelling tool used to track energy consumption, production, and resource extraction	✓		✓
MARKAL/ TIMES	Economic-environmental optimization model for least-cost planning of energy systems			✓
GIZ (Deutsche Gesellschaft fur Internationale Zusammenarbeit) Mini-grid Builder	Performs energy demand calculations and required generation capacity	✓		
MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact)	Medium-to long-term energy system planning, energy policy analysis and scenario development		✓	✓
Network Planner	Used for least-cost planning for grid, mini-grid, and off-grid systems			✓
Paladin DesignBase	Simulation platform for modelling, analysing, and optimizing power system performance	✓	✓	
RETScreen	Used to determine whether a proposed renewable energy, or energy efficiency project is financially viable	✓		

REDEO (Rural Electrification Decentralized Energy Options)	Handles off-grid systems used to compare various distributed power generation options	✓		
WASP (Wien Automatic System Planning)	Expansion plan optimization model for electricity generation	✓	✓	✓
INSEL (Integrated Simulation Environment Language)	Simulation program for grid-connected and stand-alone PV systems	✓	✓	

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