IRENA

International Renewable Energy Agency

E-LEARNING COURSE ON POLICY AND REGULATORY FRAMEWORKS FOR RENEWABLES-BASED MINI-GRIDS

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org

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Disclaimer

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INTRODUCTION TO THE COURSE

Renewables-based mini-grids are increasingly recognised as a means to expand electricity access in a timely, sustainable and cost-effective manner. Appropriate **policy and regulatory frameworks** are a necessary pre-condition to address investment risks, scale up deployment and ensure mini-grid operations are sustainable in the long term. Developing and implementing these frameworks in turn requires strengthening the capacity of policy makers.

This course is designed for mini-grid policy makers and regulators, as well as developers and community leaders.

COURSE OBJECTIVES

The course focuses on the policy and regulatory frameworks needed to support the successful deployment of renewables-based mini-grids. The main objectives of the course are to:

- explain what mini-grids are, and outline the various types in operation;
- explain the critical role of mini-grids in achieving universal access to electricity, especially in remote rural communities;
- outline the role of policies and regulations in the development of mini-grids;
- discuss the necessary elements of an enabling environment for sustainable renewable-energy-based mini-grids; and
- provide pointers on how to implement relevant policies and regulations, highlighting best practices from both successful and unsuccessful mini-grid projects around the world.

Upon successful completion of the course, students will have gained an understanding of the role of policy and regulations in the development of mini-grids using sustainable renewable energy sources. They will also appreciate best practices in mini-grid development, underpinned by clear policies and regulations. Equally important, they will have learnt about the pitfalls to avoid in policy development and implementation.

COURSE STRUCTURE

The course is divided into five modules, each consisting of three to five units.

The course begins with a general introduction to mini-grid policy and regulations. Next, Module 2 considers key areas of regulation. Module 3 outlines the key actors and institutions involved in the deployment of mini-grids. Module 4 focuses on how to create an ecosystem for successful mini-grid deployment. The fifth, and final, module discusses mechanisms for the implementation of mini-grids. In summary:

- Module 1 – Introduction to mini-grid policy and regulations
- Module 2 – Areas of regulation
- Module 3 – Key actors and institutions
- Module 4 – Creating an ecosystem for successful mini-grids
- Module 5 – Implementation mechanisms

NAVIGATING THE COURSE

The course can be taken by going through the provided course material, recommended reading and case studies. Each module concludes with reflections on the topics covered and a quiz. It is expected that the course will take about 100 hours of study, including the quizzes.

COURSE COMPLETION

Course completion requires going through all the materials and scoring higher than 75% on the quizzes.

MODULE 1 – INTRODUCTION TO MINI-GRID POLICY AND REGULATIONS

MODULE 1 OBJECTIVES

This is the first module of IRENA's e-learning course on policy and regulatory frameworks supporting renewables-based mini-grids. The module aims to provide an understanding of the importance of formulating clear policies and regulations to guide the development and deployment of mini-grids and to ensure their sustainability. Examples from around the world will be used to illustrate good practices and also pitfalls to be avoided. In summary, the module's objectives are to:

- Help build a sound understanding of the role of policies and regulations in supporting renewables-based mini-grids.
- Define key differences between policy and regulation.
- Discuss the importance of formulating clear policies to guide the development of mini-grids.
- Discuss the role of regulations in the implementation of mini-grids.

MODULE OUTLINE

The module consists of three units:

- Unit 1 – Introduction to mini-grids
- Unit 2 – Role of policies and regulations in mini-grid development
- Unit 3 – Types of mini-grids

Unit 1 introduces the concept of mini-grids. Next, Unit 2 discusses the role of policy and regulations in the development of mini-grids. Unit 3 outlines the several available types of mini-grids, and discusses their advantages and drawbacks.

Clear policies and regulations are critical to the development of sustainable mini-grids.

UNIT 1 – INTRODUCTION TO MINI-GRIDS

This unit covers two main topics. First, the technical aspects of mini-grids are defined. Next, the questions of why mini-grids are needed and what their role is in rural electrification are addressed.

Starting with the first topic: What is a mini-grid? One common definition of a mini-grid is an electricity supply system consisting of local generation satisfying local demand, with distribution voltage limited to 11 kilovolts (kV).

A mini-grid is an electricity supply system consisting of local generation satisfying local demand, with distribution limited to a low voltage of up to 11 kV.

The World Bank's Multi-Tier Framework (MTF) provides a means for assessing the electricity service provided by mini-grids. It categorises access to electricity into five tiers, ranging from no access to high-quality electricity service, as shown in Table 1. This approach helps capture the diversity of electricity access across countries and regions, taking into account factors such as the reliability, affordability and quality of service.

THE MULTI-TIER FRAMEWORK FOR ELECTRICITY ACCESS

The Multi-Tier Framework for electricity access is a tool used to assess and categorise the level of access to electricity in different regions or countries. The tool, developed by the World Bank, provides a clear and structured way of evaluating electricity access and measuring progress in improving access for populations worldwide.

For mini-grids, the MTF can be applied to assess service quality, which may be at the level of the main grid or slightly lower. The quality of supply has cost implications: the higher the tier level, the higher the cost.

Table 1 The World Bank's Multi-Tier Framework

TIER LEVEL	DESCRIPTION	INDICATORS
Tier 0: No access	No access to electricity	• People are without any access to electricity, instead relying on conventional energy sources like kerosene, candles or other non-electric solutions.
Tier 1: Very basic access	Access to electricity for limited purposes, but with extremely poor quality	• Supply of electricity may be very intermittent. • Usage might be restricted to a few hours a day. • Voltage and frequency may not be stable.
Tier 2: Basic access	Access to electricity but with limited reliability, quality and hours of supply	• Basic lighting and small appliances can be used. • Some homes can access electricity, but outages are frequent. • Limited ability to use high-demand appliances (*e.g*. refrigeration).
Tier 3: Intermediate access	Reliable and regular electricity supply but still with some limitations in terms of meeting larger demand	• Reliable and consistent supply for several hours every day (*e.g*. 6-12 hours). • Power is enough to support lighting, basic appliances and some productive uses (*e.g*. small refrigerator, television or phone charging). • The quality of electricity is generally stable, but there may still be occasional interruptions.
Tier 4: Advanced access	High-quality, reliable electricity supply, which can support most household and small business activities	• 24/7 access to electricity. • Can support large appliances like refrigerators and air conditioners, and even small enterprises. • The quality of service is reliable, and interruptions are minimal.
Tier 5: Full access	Full and continuous access to electricity with very high reliability and capacity to support all energy needs	• 24/7 access with minimal disruptions. • High-quality service capable of powering all household, business and industrial needs. • The electricity supply is very stable and capable of supporting diverse needs, including high-power industrial applications.

Important uses of the Multi-Tier Framework

The MTF may be used for:

- **Assessment.** The MTF allows policy makers, development agencies and governments to assess the level of electricity access and identify priorities for investment. The MTF can be used to guide the design of mini-grids, optimising quality and reliability.
- **Targeting.** Assessing the performance of mini-grids through the lens of the MTF enables easier evaluation of areas where mini-grid performance needs to improve. Key priorities might include increasing supply, reliability or the number of households with access.
- **Tracking progress.** The framework enables tracking progress in improving access to electricity over time, in line with global goals such as Sustainable Development Goal (SDG) 7.

Generation technology and modes of deployment

A wide range of technologies, including diesel, hydro, solar, wind or hybrid solutions incorporating battery energy storage, or their combinations, can be used for power generation in mini-grids.

Mini-grids can operate either in parallel with the main utility power grid or in an "islanded" mode, that is, disconnected from the existing grid. Parallel operation is often referred to as on-grid, whereas islanded operation is referred to as off-grid. Off-grid mini-grids are more commonly deployed and more economical in remote communities far from utility grids. The general trend is for such off-grid systems to be based on renewable energy sources, often a hybrid of solar photovoltaic (PV) and battery storage. It is for this reason that the focus of this course is on renewables-based mini-grids.

Why are mini-grids important?

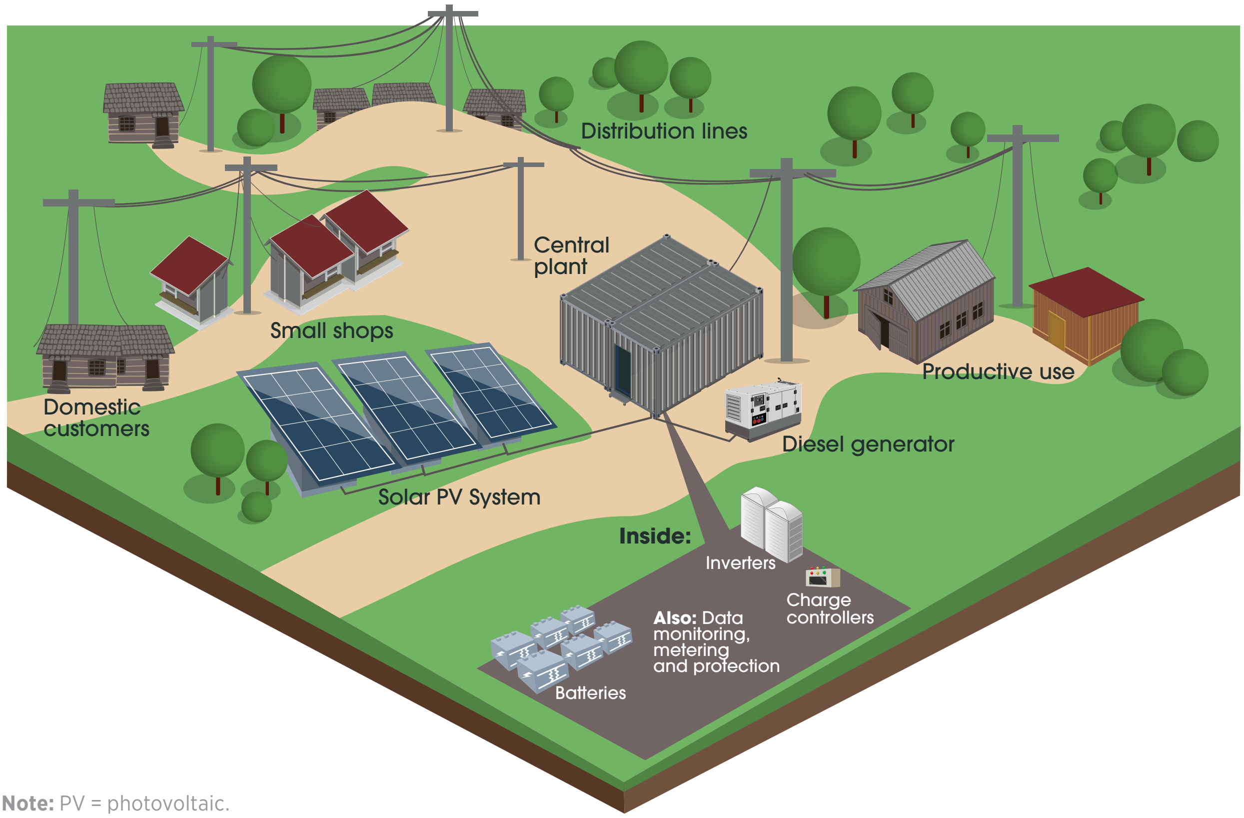
Despite accelerating efforts towards universal access, the world still has over 660 million people without access to electricity, most of whom live in remote rural communities. Grid expansion can bring electricity to rural communities, but at very high costs – between USD 19 000 and USD 22 000/kilometre (km) for transmission and USD 9 000/km for distribution. On average, rural populations live 20 km away from the nearest substation. Recovering costs through connection fees is economically feasible where five to ten connections per kilometre of expansion are anticipated, but this is generally not the case in rural communities. In countries where the grid has been extended to rural areas, affordability remains an issue, as only 10 - 20% of possible connections are realised. In some cases, electricity supply is available, but the target consumer is unable to afford the connection fee. For details on an example from Zambia, refer to the Study of Major Solar Energy Mini-Grid Initiatives in Zambia (Kapole *et al.*, 2023).

Inadequate regulation is the reason the affordability of connection fees is a serious concern for new customers. Regulations should be able to mandate utilities to spread out the connection fee for consumers, payable in monthly dues over an extended period – for instance, three to five years. This would make the fee affordable.

Meanwhile, in geographically isolated regions where extending the main grid is economically prohibitive, mini-grids can be deployed, bringing electricity to underserved communities. Mini-grids thus play an important role in efforts towards universal access to electricity. For more information on the role and cost of mini-grids, refer to the report Micro-Grids – Empowering Communities and Enabling Transformation in Africa (AUDA NEPAD, 2018) of the New Partnership for Africa's Development (NEPAD).

Off-grid mini-grids, utilising renewable energy resources, allow for flexibility in system design and scale and are less capital intensive than grid expansion. The falling costs of energy storage and renewable energy technologies are helping to make renewables-based mini-grids even more cost-effective. Grid expansion is a viable option for about 30% of Africa's rural communities, while mini-grids are expected to be the route to electrification for 45%. The rest, mostly remote and sparsely populated communities, can be electrified through solar home systems.

Figure 1 The typical set-up of a mini-grid



Note: PV = photovoltaic.

UNIT 2 – ROLE OF POLICY AND REGULATIONS IN MINI-GRID DEVELOPMENT

This unit will first discuss the importance of clear policies in mini-grid development, before turning to the topic of regulations. In summary, the unit outlines:

- Key differences between policies and regulations relevant to mini-grids,
- The role of policy in mini-grid development and
- The role of regulations in mini-grid development.

Policies and regulations: Key differences

Policies and regulations are both essential components of governance, but they serve distinct functions and are developed through different processes.

- **Policy** refers to a set of principles, guidelines or documents adopted by a government or organisation to address specific issues or achieve established objectives. Policies provide a framework for decision making and guide actions within an organisation or government. They are often broad in scope but may not be legally binding. For example, a government might adopt a policy to promote renewable energy sources that outlines general goals and intentions but does not specify the exact measures to be taken.
- **Regulations,** on the other hand, refer to specific rules or directives issued by an authorised body, such as a government agency, for the implementation and enforcement of laws or policies. Regulations are legally binding and provide detailed instructions on how broader policies are to be applied. They are designed to ensure compliance with the law and often include penalties for non-compliance. For instance, following the adoption of a policy to promote renewable energy, a government agency might issue regulations specifying the technical standards for solar panel installations.

In summary, while policies set the overarching goals and direction, regulations provide the specific rules and procedures necessary to achieve those goals. Policies are typically broader and more flexible, whereas regulations are detailed and enforceable.

Role of policy in mini-grid development

Policies play a crucial role in the development of mini-grids. They establish the framework and incentives necessary to successfully implement and operate mini-grids. Mini-grid policies encompass a number of different mechanisms, outlined below.

- **A policy framework:** Policies define the legal and regulatory environment for mini-grids, covering aspects such as licensing, tariff setting and quality standards. A robust policy framework addresses investment risks and ensures that mini-grids operate efficiently and sustainably.
- **Financial incentives:** Government policies can provide financial support mechanisms, such as subsidies, grants or favourable financing terms, to encourage private sector investment in mini-grids. These incentives help reduce the financial risks associated with mini-grid projects and make them more attractive to investors.
- **Non-financial incentives:** Policies can also provide non-financial incentives to stimulate mini-grid development by addressing various barriers and fostering a conducive environment for investment and operation. These incentives include regulatory reforms, technical assistance, capacity building and community engagement.
- **Grid integration and expansion:** Policies can outline procedures for integrating mini-grids with the main grid. Among others, they can include technical standards and mechanisms to compensate mini-grid operators when the main grid arrives. This ensures a seamless transition and continued service for consumers.
- **Capacity building**: Effective policies build the capacity of all stakeholders involved in mini-grid development, from mini-grid developers and financing institutions to local communities, including through training and resources, to ensure they have the skills and knowledge to develop, operate and maintain mini-grids effectively. Capacity building should be structured, with appropriate certification for installation technicians, to prevent poor installation by unqualified installers. Technical and vocational education and training institutions, the institutions responsible for tertiary education, could be tasked with developing a curricular and certification framework.
- **Demand risk mitigation:** Policy makers need to balance the level of government control over mini-grid deployment with the financial contribution the government is willing to make and the tariff level that it is ready to accept. Introducing demand risk mitigation instruments in the policy framework is important, as demand growth in rural areas can be difficult to predict.

In conclusion, well-designed policies are essential for creating an enabling environment for the development of mini-grids, to address financial, technical and operational challenges and ensure that mini-grids contribute to expanding energy access effectively.

Role of regulations in mini-grid development

Regulations are fundamental to the development and operation of mini-grids. They establish the legal and technical frameworks necessary for their successful development and operation. Regulations relevant to mini-grids are of various types, outlined below.

- **Licensing and legal framework:** Regulations define the licensing requirements for mini-grid operators. They ensure that only qualified entities can develop and manage mini-grids. A legal framework clarifies the rights and responsibilities of operators and fosters a stable environment for investment. It is worth noting that, in practice, licensing is usually required for large mini-grids, whereas small projects only need to be registered. While a license provides official permission to develop and operate a mini-grid and is granted only after prescribed requirements are met, registration is less stringent and simply proves that the mini-grid is officially recognised and recorded.

- **Tariffs and financial viability:** Regulatory bodies are responsible for establishing tariff structures that balance affordability for consumers with the financial sustainability of mini-grid operators. Well-designed tariffs are essential for attracting investment and ensuring mini-grids remain viable in the long term. This often requires careful consideration of assistance for low-income communities, either in the form of capital or operating subsidies.
- **Quality Standards and consumer protection:** In the context of mini-grid regulations, addressing grievances is an essential part of ensuring fairness, transparency and accountability. Standard customer contracts include clearly outlined processes for addressing grievances, including response timelines and dispute resolution methods. Some clauses make it possible to escalate issues to higher authorities or to request independent arbitration if they are not resolved within a certain time frame.
- Grievance redress mechanisms typically seek to provide a structured way for stakeholders – especially customers, operators and developers – to resolve disputes or raise concerns. They may include several key components:
  - A dedicated phone number or online platform where customers can lodge complaints or grievances related to service, billing, infrastructure or other issues. Some digital platforms allow customers to track the status of their grievances and receive resolutions. Such platforms might also allow customers to register their feedback so that their experiences are continuously monitored and improved. In addition, some mini-grid operators use social media channels as a way to address grievances in real time and improve customer satisfaction.
  - A mailing address that customers can use to submit grievances regarding any issues they face with the mini-grid system – including delays, unfair pricing or poor service quality – in writing.
  - In cases where direct negotiation between parties (e.g. mini-grid operator and customer) fails, a neutral third party could mediate to help both parties come to a fair resolution.
  - For more serious or unresolved issues, an arbitration process could be initiated, where an arbitrator makes a final and binding decision on the grievance – this is often faster than going through a full court process.
  - Using a transparent mechanism, such as a public grievance tracker or database, customers can check the status of their complaints and see how many grievances have been resolved. This helps ensure accountability.
  - Operators might be required to publish annual reports detailing the number and types of grievances received, how they were resolved, and any trends or systemic issues that need addressing.
  - In cases where mini-grid services fail to meet agreed standards (e.g. due to excessive downtime or poor-quality service), regulations may include provisions for compensating consumers monetarily, through service credits or through rebates.
  - Regulations should also specify the maximum duration within which a grievance must be acknowledged and resolved, ensuring timely response from mini-grid operators. Regulations may also establish penalties for mini-grid operators that fail to adequately address grievances. Such penalties incentivise operators to improve complaint handling.

By implementing a combination of these mechanisms, mini-grid regulators can ensure that grievances are addressed effectively, and stakeholders are satisfied with the services.

Several organisations and regulatory bodies, as outlined below, may be involved in the grievance redress process.

- Energy regulatory authority: An independent body overseeing mini-grid operations with the authority to handle complaints. It could intervene when complaints are not resolved satisfactorily at the operator level.
- Public grievance commission: A government-appointed commission tasked with overseeing all complaints related to energy services, including mini-grids. This body may have the power to investigate complaints, mediate disputes and ensure compliance with regulations.
- Community engagement forums bring together operators, regulators and community members to discuss ongoing issues, expectations and grievances. They serve as platforms for stakeholders to voice their concerns and seek solutions collaboratively.
- Advisory committees, composed of both operators and consumers, meet regularly to review performance, address concerns and recommend improvements to the mini-grid service.

IMPORTANCE OF REGULATIONS

Regulations set the technical standards for mini-grid infrastructure and operations, ensuring a reliable and safe electricity supply. They also protect consumers by defining service quality expectations.

- **Grid integration and expansion**. Regulations outline procedures for integrating mini-grids with the main grid. For example, they specify technical standards and include compensation mechanisms for mini-grid operators when the main grid arrives. This ensures a seamless transition and continued service reliability for consumers.
- **Capacity building and standardisation.** Regulatory frameworks often include provisions for capacity building among stakeholders and for the development of standardised procedures and templates. Together, standardisation and capacity building promote uniformity and efficiency across the mini-grid sector.

In conclusion, well-thought-out regulations provide the necessary legal and technical framework that ensures mini-grids operate efficiently, sustainably and in the best interests of both operators and consumers.

UNIT 3 – TYPES AND FORMS OF MINI-GRIDS

There are two types of mini-grids – direct current (DC) mini-grids and alternating current (AC) mini-grids. This unit briefly discusses the differences between the two and their distinctive features.

DC mini-grids

A DC mini-grid is a localised electricity distribution system that generates, stores and supplies electric power using **direct current**. Unlike traditional AC grids, DC mini-grids are particularly well suited for integrating renewable energy sources like solar PV, which naturally produce DC power. Their key features include the following.

- **Simplified system architecture:** DC mini-grids often have a more straightforward design than AC systems, given their limited requirements in terms of power control and management.
- **Energy storage:** DC mini-grid systems typically incorporate energy storage solutions (*e.g.* batteries) to ensure a consistent and reliable power supply, especially when renewable generation is low, or when demand is high.
- **Distribution:** In a system of DC mini-grids, the energy produced by the generation source is carried to end users over a distribution network, often utilising low-voltage DC wiring. When DC powers appliances, the distribution of DC can reduce energy losses and improve overall efficiency by eliminating conversion losses.

A key **advantage** of DC mini-grids is their compatibility with DC appliances. Many household appliances – including lighting and electronic devices such as televisions, computers, laptops and mobile phones – are inherently DC devices. This makes DC mini-grids good for rural and remote areas. Another advantage of DC mini-grids is reduced conversion losses. By eliminating the need to convert from DC to AC, DC mini-grids can achieve higher efficiency, especially when DC appliances/devices are used.

DC mini-grids have the following **disadvantages**.

- **Limited long-distance transmission:** It may be difficult to transmit the electricity produced by DC mini-grids over long distances at low voltages. For this, the use of solid-state transformers is being explored, which allow DC mini-grids and the DC main grid to operate while isolating both systems against faults.
- **Grid integration:** While DC mini-grids are more suitable for off-grid applications, their connection to the national grid is beginning to be explored and is in the early phases of development.
- **Protection challenges:** Unlike AC systems, which are easier to protect because their voltages and currents typically vary in a sinusoidal pattern, which allows for easy circuit breaking, DC systems require special protection.
- **Mismatch with most appliances:** It is also worth highlighting that appliances and equipment are mass manufactured for AC mini-grids. It is much harder to find DC appliances, and they can be costlier, since the market is smaller.

In summary, DC mini-grids offer a promising solution for providing reliable and efficient electricity to off-grid communities, especially in areas where renewable energy sources are abundant. However, it is worth noting that although solar PV naturally generates DC power and some of the most-used off-grid appliances are inherently DC powered, applications of DC mini-grids are quite rare in developing countries.

Examples of DC mini-grids

Key companies installing DC mini-grids (Kapole *et al*., 2023) include the following:

- **Meshpower:** Meshpower has installed seven solar PV DC micro-grids in Rwanda. The micro-grids provide power for lighting and mobile phone charging for up to two to three hours a day. Meshpower is applying the same model in India.
- **Cygni:** Cygni is headquartered in Hyderabad, India. By 2018, it had implemented DC systems in 816 villages across nine states servicing 19 000 homes.
- **The Energy and Resources Institute (TERI):** By 2014, TERI had installed 30 DC micro-grids in Uttar Pradesh (India), providing 130 households and 1 100 business units with light-emitting diode-based lighting (four hours per day, one to three lights per household) and mobile phone charging. Costs averaged INR 2 000 000 per 50 households connected.
- **Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA):** In 2011-2012, UPNEDA installed 23 DC solar PV micro-grids in Uttar Pradesh, India, covering roughly 4 000 families. Electricity provision is limited to four to five hours in the evening, with two LED lamps and mobile charging for households.
- **Minda:** Minda has installed 13 DC solar PV micro-grids in India to date. Electricity is primarily provided for lighting (two LED lamps per household). Installation costs averaged around INR 360 000 per 40 households.
- **Solaric:** Solaric installs DC micro-grids, utilising 1.5-3 kilowatt peak PV systems. The company is active in Bangladesh, India, Nepal and Malaysia.

AC mini-grids

AC mini-grids offer several advantages. Among other benefits, the power supply in remote areas is more reliable and the power is of better quality, they are flexible in integrating diverse renewable energy sources, they show cost-effectiveness in meeting local power needs, energy security is enhanced through independent operation and they are compatible with existing household appliances because they output AC power. These advantages make AC mini-grids a viable solution for electrifying off-grid communities and providing backup power during grid outages. Most mini-grids are AC based.

The advantages of AC mini-grids can be summarised as follows.

The advantages of AC mini-grids can be summarised as follows.

- **Easy access to AC devices and appliances,** since most electric power supply systems are AC based.
- **Renewable energy integration:** AC mini-grids readily integrate various renewable energy sources, such as solar, wind and hydro power, promoting clean energy generation and reducing the carbon footprint.
- **Improved reliability:** By operating independently, AC mini-grids can provide consistent power supply even during disruptions on the main grid. This boosts energy security.
- **Scalability and flexibility:** Mini-grids can be sized to match local demand and easily expanded as energy needs grow within a community.
- **Local control and community engagement:** Mini-grids can be managed by local communities, which are in turn empowered to participate in energy decision making.
- **Reduced transmission losses:** By generating electricity closer to the point of consumption, AC mini-grids minimise energy losses during transmission.
- **Improved power quality:** AC mini-grids can provide more stable voltage compared with fluctuating grid power in some areas.

The main **disadvantage** of AC mini-grids is related to their efficiency. Connecting inherently DC devices such as televisions, laptops and computers to an AC supply system increases losses due to conversion from alternating current to direct current.

Another challenge with AC mini-grids is that all generation sources need to be synchronised, and frequency needs to be regulated. This is not the case with DC mini-grids.

MODULE 1 REFLECTIONS

- *Select any developing country and assess the progress it has made towards universal access to electrification. What role have different electrification methods (grid connections, mini-grids and solar home systems) played in their progress towards universal access?*
- *Would you regard populations with Tier 1 electricity access, such as those accessing electricity typically using solar home systems, as being electrified? What are your thoughts on such populations being considered as part of the progress towards SDG 7?*
- *Based on your understanding of the topics covered in this module, why do some mini-grids deployed in remote impoverished rural communities in developing countries become unsustainable?*
- *State five reasons why clear policies are important in the development of mini-grid regulations.*
- *Why do you think DC mini-grids are not prevalent despite their relative advantages over AC mini-grids?*

MODULE 1 RECOMMENDED READING

1. *Clean Energy Mini-Grid Policy Development Guide* (UNIDO, 2020)
2. *Scaling Up Access to Electricity: Emerging Best Practices for Mini-Grid Regulation* (ESMAP, 2015a)
3. *Policies and Regulations for Mini-Grids* (IRENA, 2018)
4. *Micro-Grids – Empowering Communities and Enabling Transformation in Africa* (AUDA NEPAD, 2018)
5. *DC Mini-Grids* (Energypedia, 2025)
6. *Renewable Mini-Grids Innovation Landscape Brief* (IRENA, 2019)
7. *DC Mini-Grids* (Turner, 2017)
8. *Mini-Grid Regulations for Private Investment* (Yang, Khandelwal and Pumarejo, 2021)
9. *Scaling Up Access to Electricity: Emerging Best Practices for Mini-Grid Regulation* (ESMAP, 2015b)
10. *Mini-Grid Policy and Regulation* (AfDB, 2020)
11. *Innovation Outlook Renewable Mini-Grids Summary for Policy Makers* (IRENA, 2016)
12. *Cost Projections for Utility-Scale Battery Storage* (NREL, 2023)

MODULE 1 QUIZ

1. **Which of the following would qualify as policy-related factors in the development of mini-grids?**
   a. Outlining procedures for integrating mini-grids with the main grid
   b. Establishing tariff structures
   c. Providing financial support mechanisms, such as subsidies, grants or favourable financing terms

2. **Which of the following are considered regulatory aspects of mini-grid development?**
   a. Establishing a licensing and legal framework
   b. Outlining procedures for integrating mini-grids with the main grid
   c. Balancing the level of government control over mini-grid deployment

3. **Who is responsible for the development of mini-grid policy?**
   a. Government
   b. Private sector
   c. Independent power producers

4. **Which type of mini-grids among those listed below is the most common?**
   a. DC
   b. AC
   c. AC and DC hybrid

5. **What are the main limitations of DC mini-grids?**
   a. There are a lot of DC appliances.
   b. They can be applied over long distances.
   c. Protection is difficult.

6. **What are the advantages of AC mini-grids?**
   a. AC appliances are more commonly used.
   b. They have low losses.
   c. They have high losses.
   d. They are easy to protect.

7. **Which of the following sizes of off-grid systems represent the upper limit of mini-grid capacity? (Refer to *Innovation landscape brief: Renewable mini-grids*)**
   a. 100 W
   b. 1 000 W
   c. 10 kW
   d. 100 MW
   e. 1 000 MW

8. **How can mini-grids based on variable renewable energy sources such as solar and wind be stably operated?**
   a. Reduce demand when wind and solar are not available
   b. Use a system to store energy for use when wind is not blowing or the sun is not shining
   c. Use a hybrid solar-wind system

9. **Which of the following are advantages of mini-grids?**
   a. Reduce transmission losses
   b. Scalable
   c. Increase the reliability of local supply

10. **Why are mini-grids important?**
   a. They are a cost-effective solution for supplying electricity to remote rural communities.
   b. They are better than the main grid.
   c. They are less expensive than the main grid.

MODULE 2 – AREAS OF REGULATION

RECAP OF MODULE 1

Module 1 introduced the concept of mini-grids and provided a rationale for them. Mini-grids are critical if remote rural communities are to stand a chance of being electrified by 2030 – the Sustainable Development Goal (SDG) 7 target of universal access to electricity around the world. The module covered the following key topics:

1. The roles of, and differences between, policies and regulations for mini-grids. Policies provide the overarching national objective for mini-grids, whereas regulations set clear rules for their deployment and operation in a manner consistent with mini-grid policies.
2. The definition of two types of mini-grids, direct current (DC) and alternating current (AC) mini-grids, and their advantages and drawbacks.

Module 1 provided a firm foundation for understanding the material presented in Module 2, which is focused on areas of regulation.

MODULE 2 OBJECTIVES

This is the second module of IRENA's e-learning course on policy and regulatory frameworks for renewable-energy-based mini-grids. It discusses five areas of mini-grid regulation: (1) regulation for market entry, (2) tariff regulation and related issues, (3) standards for the technical specifications of mini-grids, (4) critical issues related to the arrival of the main grid and (5) what can and should be done to support end users of mini-grid services. By the end of this module, students will have gained a thorough understanding of these areas of mini-grid regulation and how they apply to the planning, deployment and operation of mini-grids.

MODULE 2 OUTLINE

This module on mini-grid regulation consists of five units:

- Unit 1 – Market entry
- Unit 2 – Tariffs
- Unit 3 – Technical specifications
- Unit 4 – What happens when grid integration occurs?
- Unit 5 – Supporting end users

The first unit will present issues related to the market entry of mini-grids. Next, the second unit discusses mini-grid tariffs. The third unit presents issues related to the technical specifications of mini-grids. A critical issue to consider is what happens when the main grid arrives. This is discussed in the fourth unit, alongside several international examples of best practices. The fifth, and the last, unit is focused on support to end users, including how their needs can be included in mini-grid regulations.

UNIT 1 – MARKET ENTRY

Entry into the mini-grid market can be challenging due to a number of technical, financial, regulatory and social factors, outlined below.

High initial capital costs

Renewable-energy-based mini-grids require significant up-front investment in generation, mainly in solar panels and wind turbines, and in battery energy storage systems (BESSs). Additional investments are needed in distribution infrastructure to ensure that electricity supply from the mini-grids reaches the intended end users.

High capital costs could discourage investment in mini-grids, especially in low-income communities with uncertain revenue streams, which remote rural areas tend to be. Providing mini-grid developers access to concessional financing, grants or blended finance could help lower this barrier to market entry.

Regulatory and policy barriers

Lack of clarity or inconsistencies in regulations can create uncertainty for developers. Challenges include (1) a lack of clear tariff approval processes, (2) restrictions, if any, on private sector participation and (3) complex licensing and permitting requirements, all of which can delay project implementation and push up costs.

To create an enabling environment, governments should establish clear, supportive policies and streamline regulatory processes.

Financial viability and revenue risks

Among the main challenges in mini-grid development and deployment is ensuring sufficient revenue to cover developers' costs in areas with low demand. Mini-grids are, in most cases, deployed in remote rural communities, where both electricity consumption levels and potential customers' willingness to pay (WTP) for services are low. This combination of low demand and low WTP makes it difficult for mini-grids to achieve financial sustainability.

Several approaches can be used to ensure consistent revenue collection in low-income areas, thereby maximising revenue collection and minimising payment defaults. One approach is to make use of tiered tariffs, where higher tariffs are charged for higher levels of consumption, on the plausible assumption that higher consumption has a direct correlation with affluency and ability to pay the higher tariff. The lowest-tariff tier would be the so-called lifeline tariff. The other solution is to use anchor loads, for example, businesses, which have a steady income and the ability to pay. Community engagement to foster a sense of ownership is yet another approach towards improving revenue collection.

Technical challenges

The deployment and maintenance of reliable mini-grids in remote areas comes with some technical challenges. Among them is a lack or limited availability of technical expertise to operate and maintain the systems within local communities. Another challenge is environmental conditions, which can be harsh, due to, for example, extreme weather. These challenges push up the costs of operating mini-grid systems and trigger potentially prolonged outages because technical experts have to be brought in from outside the community.

Key solutions to these challenges are to train local technicians and to use robust, modular systems that show resilience even when operated in harsh environments.

Social and cultural factors

Gaining community trust and acceptance is an important consideration in the deployment of mini-grids. Community members might show resistance to new technology. Misalignment between project objectives and local needs and expectations can be a significant barrier to the entry of mini-grid developers. These factors could translate into low adoption rates and payment defaults.

An effective solution is to engage communities early and involve them in decision making. Educating the community on the benefits of mini-grids is essential.

Access to financing

Another barrier to market entry is difficulty securing funding due to perceived risks. This is typically because rural electrification projects have high perceived risk and developers have limited or a lack of suitable collateral. This slows down market entry and delays projects. The solution is to develop risk-sharing mechanisms, such as guarantees or first-loss provisions to attract investors.

Grid extension risk

Another risk that has been identified, which can be a significant barrier to entering the mini-grid market, is the possibility of future grid extension by the national utility. If this risk is not managed well and planned for, the arrival of the main grid could render mini-grids redundant. This risk diminishes potential investors' confidence, leaving them reluctant to invest. It is therefore vital to establish clear policies on grid integration or compensation for mini-grid operators in case the main grid extends to their area.

Supply chain and logistics

The deployment of mini-grids in remote rural communities carries some challenges related to difficulty sourcing equipment and transporting it to hard-to-reach areas. High transportation costs and limited availability of quality components are clear challenges that push up costs and delay projects. To mitigate these supply chain and logistical challenges, it is advisable to develop local supply chains and use modular, easy-to-transport systems.

Lack of data and planning tools

Availability of data on energy demand, resource availability and consumer behaviour is limited in remote areas. This constitutes a critical challenge in planning mini-grids for application in these areas. The lack of these data poses challenges in designing optimal systems and predicting revenue. Investment in data collection and the use of advanced planning tools for site selection and system design are important.

Competition from alternative solutions

Mini-grids can face competition mainly from stand-alone solar systems (*e.g.* solar home systems) or from diesel generators. When such alternatives are accessible, the demand for mini-grid connections is diminished. Highlighting the advantages of mini-grids, such as higher power capacity and reliability, can give them an edge over competition. Fiscal measures such as tax incentives for mini-grid developers (*e.g.* waivers and rebates) and reduced fossil fuel subsidies can also help.

Environmental and land use issues

The development of mini-grids based on renewable energy, especially solar photovoltaic (PV), which typically has a large footprint per megawatt (MW), can be a challenge. Land acquisition can be a major hurdle and will be governed by the rules applicable in the country. In some countries, the consent of traditional rulers (*e.g.* chiefs), who superintend on traditional land rather than the state, is a must. Further, PV arrays may require land to be graded so that it is flat and surrounding trees or other sources of shade to be removed. Understanding the rules and processes involved in land acquisition is important. Environmental concerns related to the use of resources (*e.g.* water for hydropower) or land should also be considered from the outset.

These concerns could delay projects due to the requirements of environmental impact assessments and extensive community engagement. Where environmental impact assessments and community engagement are inadequate, mini-grids could face opposition from the community. Conducting thorough environmental and social impact assessments and engaging stakeholders early are important to secure community buy-in.

Scalability and replicability

Scalability and replicability are important market considerations for mini-grid projects. Varying local conditions could pose challenges to scaling up successful mini-grid pilot projects, limiting their market growth. One solution is to develop standardised, modular systems that can be adapted to different contexts.

Political and economic instability

Political stability and economic downturns are other critical considerations when entering the mini-grid market. They can disrupt projects and tend to increase the risk for investors and developers. One solution is to partner with international organisations or development agencies, which are then able to mitigate the risks.

Conclusion

Entry into the mini-grid market requires addressing a complex set of challenges. Successful entry often involves a combination of supportive policies, innovative financing mechanisms, community engagement and robust technical solutions. For mini-grids to thrive, governments, developers and investors must collaborate to create an enabling environment. Only then can they be able to expand access to electricity in underserved rural areas.

UNIT 2 – TARIFFS

Tariffs for mini-grids refer to the pricing structure for the electricity supplied by a mini-grid system. While tariffs are crucial for ensuring the financial sustainability of mini-grids, they must also address the affordability and reliability of the electricity supplied to users. Key aspects considered in the process of tariff setting include the following.

- **Capital costs:** Initial investment in generation, storage and distribution infrastructure.
- **Operating and maintenance costs:** Regular maintenance, repairs and labour.
- **Fuel costs:** For hybrid systems using diesel or other fuels.
- **Battery replacement costs:** Periodic replacement of energy storage systems.
- **Demand profile:** Energy consumption patterns of the community.
- **Scale of the mini-grid:** Larger systems may benefit from economies of scale.
- **Subsidies and incentives:** Government or donor support to reduce costs but allow sufficient return on investments.
- **Tariff structure:** Flat rates, tiered pricing or pay-as-you-go models.

The main challenge is balancing affordability with sustainability. In other words, how can one design tariffs that are low enough that users can afford but high enough that developers can cover their operating and investment costs? Tariff setting also includes an additional dimension: willingness to pay. Surveys can be conducted to determine how much users are willing to pay; this is often influenced by their current energy expenditures, for example, on kerosene, candles or diesel generators.

Below is a list of the typical tariff structures used for mini-grids:

- A **flat rate tariff** is the simplest and essentially includes a fixed price per kilowatt hour (kWh) consumed, regardless of consumption level. For example, it can be set at USD 0.30/kWh for all consumers. Clearly, it is difficult to find the right single number that would balance affordability and sustainability, especially in disparate communities with both affluent and poor households.
- A **tiered pricing regime** includes different rates based on consumption level. For example, the first 50 kWh can be priced at a lower rate, say, USD 0.20/kWh, while a higher rate of, say, USD 0.30/kWh, would apply for consumption above 50 kWh. This provides a greater degree of freedom to balance affordability and sustainability.
- Under a **time of use (ToU)** tariff structure, different rates based on the time of day and, where appropriate, season apply. For example, higher rates are applied for consumption during peak hours and lower rates for consumption during off-peak hours. This makes sense because more expensive generation might be required to meet peak demand.
- **Other possible tariff structures** include one-time payment or recurring charges for connecting to the mini-grid, or a minimum monthly charge, which ensures revenue even if consumption is low.

Mini-grid tariffs typically range from USD 0.20 to USD 0.80 /kWh, depending on system design, location and cost structure. Renewables-based systems tend to have lower tariffs (between USD 0.20 and USD 0.50/kWh), mainly due to low operating costs. Diesel-based systems have higher tariffs (between USD 0.50 and USD 0.80/kWh) due to fuel costs. The tariffs of hybrid systems fall somewhere between the tariffs for renewables- and diesel-based systems.

International examples of mini-grid tariffs include the following:

- **Africa**
  - In the United Republic of Tanzania, solar mini-grid tariffs are between USD 0.30 and USD 0.50/kWh.
  - In Kenya, hybrid mini-grid tariffs are between USD 0.20 and USD 0.40/kWh.
- **Asia**
  - In India, solar mini-grid tariffs are between USD 0.25 and USD 0.40/kWh.
  - In the Philippines, tariffs for hybrid systems range from USD 0.30 to USD 0.60/kWh.
- **Latin America**
  - In Brazil, tariffs for renewables-based mini-grids range from USD 0.20 to USD 0.35/kWh.

Tariffs must cover operating and maintenance costs and enable the recovery of capital costs. A small profit margin may be included to ensure long-term sustainability and attract private investment. In some cases, governments or donors provide subsidies to bridge the gap between affordable tariffs and cost recovery.

In many countries, mini-grid tariffs must be approved by a regulatory authority. This can include tariff caps, which some regulators impose to protect consumers. Some incentives, for example, tax exemptions or grants, may be available to reduce costs and hence lower tariffs.

Use of so-called anchor loads can often be the way to ensure the sustainability of mini-grids in impoverished rural communities. This typically entails partnering with businesses (*e.g.* telecom towers, agro-processing) to provide a stable revenue base. Another model is community ownership. Involving the community in the ownership and management of mini-grids will likely improve compliance with payment. Blended finance, combining public and private funding, can be used to reduce tariffs.

In conclusion, tariffs are a critical component of the business model for mini-grid operators. Tariffs must be carefully designed to ensure affordability as well as the financial viability of projects.

UNIT 3 – TECHNICAL SPECIFICATIONS

As already explained in Module 1, mini-grids are localised electricity generation and distribution systems that can operate independently of or in conjunction with the main power grid. They are often used in rural or remote areas, where grid extension is not feasible. Mini-grids typically have a generation capacity of **10 kW to 10 MW**. Generation capacity depends on the size of the community or industrial application.

Sources of energy

Renewables-based mini-grids mainly use solar PV, most often in combination with battery energy storage; wind and hydropower systems are less common.

- **Solar PV** is the most common source of power generation among mini-grids, due to the ubiquity of solar resources. Solar PV can be deployed almost anywhere. Because of the diurnal nature of solar resources, solar PV systems are usually deployed as a hybrid system consisting of both solar PV and BESS.
- **Wind turbines** are installed in areas with high average wind speeds. For wind power to be economically viable, a site typically needs an average annual wind speed of at least 6.5 metres/second.
- **Hydropower systems** are strictly site specific. They are deployed in communities that are reasonably close to hydro resources, that is, a river with a substantial gradient or a waterfall.

Battery storage

BESS stores excess energy for use when generation is low - for example, at night - in solar PV systems. The most common battery type is lithium-ion, mainly due to declining costs and high efficiency. Lead-acid batteries are also used and are cheaper, but they are less efficient and have a shorter lifespan than lithium-ion batteries. Typically, battery capacity ranges from 20 kWh to 500 kWh. Capacity depends on the size of the mini-grid and the demand. Sizing a solar energy storage system involves determining how many days the batteries can power the load independent of the solar panels, especially when the sky is overcast. Generally, these "days of autonomy" number two to five days at a time. Critical applications might require ten or more days. Optimising this value considers the region's climatic conditions and the specific energy consumption of the community. The most-used battery voltages are 48 volts (V), 96 V or 120 V for smaller systems and higher voltages for larger systems.

Distribution networks

The standard distribution voltages are most often low. Countries that are part of the International Electrotechnical Commission (IEC), including the United Kingdom, the European Union, Australia, New Zealand and most African countries, use simple 230 V single-phase voltage and 400-415 V three-phase voltage for domestic and small-scale commercial applications. In the United States and Canada, 120 V single-phase voltage is used for domestic loads, although larger electrical systems, such as industrial equipment and large commercial buildings, may require higher voltages. For longer-distance distribution in larger mini-grids, medium voltage of 11 kV or 33 kV is used.

As already discussed in Module 1, there are two mini-grid types: AC and DC mini-grids. AC mini-grids are the most common, mainly due to the preponderance of AC appliances in shops and in homes. For example, microwave cookers, irons and radios all connect to AC sockets in the house. DC mini-grids are used in smaller systems, especially with solar PV.

Cables are sized appropriately for load and distance and often use aluminium or copper conductors. The cables can be above ground or underground. Other key system components include:

- **Inverters,** which convert DC power from solar panels or batteries to AC power for distribution. The capacity of an inverter is matched to the generation and load. Inverter capacity ranges from 5 kW to 500 kW, for example. Inverters tend to have high efficiency, typically 95% or more.
- **Charge controllers,** a critical part of the mini-grid system that regulate battery charging from solar or other sources. The two common types of charge controllers are (1) pulse width modulation and (2) maximum power point tracking.

- **Remote monitoring systems,** which allow operators to monitor system performance and troubleshoot issues remotely. Remote monitoring requires investment in remote sensors and means of communication with the control centre. This can require internet-based technologies, including Wi-Fi, and/or the presence of a reliable cellular network.

System lifespan and maintenance

The three key mini-grid components – solar PV panels, batteries and inverters – have different lifespans. Solar PV panels built on mono-crystalline or multi-crystalline technology have the longest life expectancy, of 20-25 years. Other technologies, such as organic cells, might have shorter lifespans. Batteries, depending on type and use, can last 5-15 years. Lithium-ion batteries last longer than lead-acid batteries. Inverters have a life expectancy of 10-15 years.

Regular maintenance is required for batteries, generators and other components to ensure they remain reliable and that the components attain their design lifespans.

Regulatory and safety standards

Adherence to local and international standards (*e.g.* the standards of the International Electrotechnical Commission or Institute of Electrical and Electronics Engineers) is very important for mini-grids (and should be made mandatory). Strict compliance with safety standards is essential. Such compliance includes the provision of protection devices like circuit breakers, fuses, lightning protection and grounding systems.

Conclusion

Mini-grids are highly customisable, and their technical specifications depend on the specific needs of the community, resources available and budget. The specifications must cover key mini-grid components, namely, solar panels, inverters and batteries.

UNIT 4 – WHAT HAPPENS WHEN THE MAIN GRID ARRIVES?

The arrival of the main grid in an area served by a mini-grid can have significant implications for the mini-grid operator, the community and the overall energy ecosystem. Outcomes depend on how the situation is managed, including regulatory frameworks, technical integration and financial arrangements. Scenarios and considerations when the main grid arrives are outlined below.

Integration with the main grid

A mini-grid may be connected to the main grid when it arrives. This allows the mini-grid to operate as part of the larger network. Among other benefits, this arrangement (1) makes electricity supply from the main grid more reliable and stable and (2) makes it possible to sell excess power to the main grid, provided regulations favour this possibility.

It is, however, important to be mindful of the challenges of integrating the mini-grid with the main grid. These include technical challenges in synchronising the mini-grid with the main grid, as well as the review of protection arrangements for the mini-grid. Synchronisation would need the right equipment. Another challenge is the cost of upgrading the mini-grid infrastructure to meet the standards of the main grid. Related costs could be minimised if the mini-grid system is designed to anticipate the arrival of the main grid.

It is therefore vital to develop clear technical and regulatory guidelines for integration with the main grid. This will minimise the technical challenges of integration and the associated costs.

Takeover by the main grid

In some cases, the main grid replaces the mini-grid, and the mini-grid operator exits the market. Among other benefits, this scenario offers consumers the possibility of (1) lower tariffs if the main grid offers subsidised rates and (2) accessing a high-capacity and extensive power supply, where the main grid is of high quality and reliable.

Meanwhile, in this scenario, (1) the mini-grid operator is left with stranded assets, and (2) local control is lost and the community can no longer be involved in energy management.

To mitigate the disruption associated with this scenario, it is advisable to establish compensation mechanisms for mini-grid operators, for example, asset buyouts or transition payments. **The legal status of mini-grids after the arrival of the main grid must also be clarified.**

Governments or utilities may compensate mini-grid operators for their investments. A typical example is paying for the depreciated value of assets or providing transition grants. Meanwhile, mini-grid licences and permits would have to be transferred to the main grid.

Co-existence with the main grid

It is possible for the mini-grid to continue operating alongside the main grid, serving specific customers or providing backup power. With this approach, (1) the mini-grid operator continues to receive revenue for the services provided, and (2) reliability is increased as the mini-grid provides backup power for an unstable grid.

However, this approach has some challenges, including, (1) competition with the main grid, which may offer lower tariffs, and (2) potential underutilisation of the mini-grid, which could result in reduced revenue for the mini-grid. One solution is to provide differentiated services; for example, the main grid could target high-reliability or premium services, while the mini-grid could offer standby service when the main grid fails.

Tariff harmonisation, which entails aligning mini-grid tariffs with main grid tariffs, could help reduce unfair competition.

Technical considerations

In all the approaches outlined above, several key elements are important to consider:

- **Grid compatibility.** Ensuring that mini-grid infrastructure (*e.g.* inverters, transformers) is compatible with the main grid is very important and must be considered at the mini-grid design stage. This can be a requirement during licensing of the mini-grid.
- **Inter-connection standards.** It is important to adhere to technical standards for voltage, frequency and synchronisation. For a mini-grid to connect to the main grid, the voltage and frequency of the mini-grid must be the same as that of the main grid. As with grid compatibility, this should be considered at the mini-grid design stage.
- **Islanding capability.** Mini-grids should ideally be designed to operate independently (in so-called islanded mode) if the main grid fails. It is desirable to maintain the mini-grid in operation should the main grid fail, as long as the fault/disturbance is not caused by the mini-grid.
- **Compatibility of meters.** The meters installed by the developer and those required by the main grid must be compatible.

Financial implications

The main financial implications for mini-grids when the main grid arrives are briefly discussed below:

- **Stranded assets.** Grid integration may result in financial losses for mini-grid operators if their assets become redundant. This would more likely affect generation assets, since the main grid could still use the mini-grid network, provided the technical standards are compatible with those of the main grid.
- **Revenue loss.** The mini-grid operator faces reduced revenues if customers switch to the main grid, due to lower tariffs, for example.

To prevent these financial implications, the development of mini-grids should include the formulation of transition plans for grid integration. These plans could include financial support or buyout options.

Community impact

Although not always the case, the main grid may offer more reliable or more affordable power, which will benefit the community. On the negative side, local technicians and staff employed by the mini-grid operator may lose their jobs. To mitigate the adverse impact of the main grid's arrival on the community, the community must be involved in decision making and provided training for new opportunities. Some of the opportunities could entail working on the main grid.

Best practices for managing the transition

Anticipating grid integration is always recommended. This entails engagement with regulators, utilities and communities early to plan for the arrival of the main grid. Clear policies on compensation, tariff harmonisation and technical standards must be established. This minimises the potentially disruptive impact of main grid's arrival. Consideration should also be given to hybrid operation, where the mini-grids complement the main grid. For example, mini-grids could provide backup power or serve areas where grid extension is not feasible.

Examples of best practices

- **United Republic of Tanzania:** The government has developed guidelines for mini-grid integration, including compensation for operators.
- **India:** Mini-grids are being integrated into the national grid under the Ministry of New and Renewable Energy.
- **Kenya:** Mini-grid operators are encouraged to transition to grid-connected systems with support from the Energy and Petroleum Regulatory Authority.

Conclusion

Grid integration does not necessarily mean the end of mini-grids. With proper planning, regulatory support and technical integration, mini-grids can co-exist with or transition smoothly into the main grid. The key is to balance the interests of all stakeholders – mini-grid operators, communities and utilities – while ensuring continued access to reliable and affordable electricity.

UNIT 5 – SUPPORTING END USERS

For mini-grid projects to be successful and sustainable and have a meaningful social impact, support to their end users is vital. End users of mini-grids are often in rural or underserved areas, and they may have limited experience with electricity or modern energy services. Below are key strategies to support end users in transitioning to mini-grids.

Affordable and fair tariffs

High electricity costs are a major deterrent to the use of electricity in low-income rural communities served by mini-grids. Moreover, limited cash flow in rural areas can make it difficult for users to pay for electricity.

Tiered tariffs are a solution to high electricity tariffs. Tiered tariffs make basic electricity affordable for low-income households. For low consumption, say, between 50 kWh and 100 kWh/year, an affordable tariff could be offered, with higher tariffs applied for consumption beyond this threshold. Another solution is to offer pay-as-you-go options to allow flexible payments. Subsidised tariffs for the poorest users could also be a solution. Subsidised tariffs could be through grants to support capital investments, resulting in a lower levelised cost of electricity and hence lower tariffs. Flexible payment schedules – for example, daily, weekly or monthly payments – could also help ameliorate cash flow problems. Discounts or incentives for timely payments could incentivise users to settle their bills in a timely manner.

Community engagement and education

Some communities may lack awareness of the full benefits of electricity. Communities must be educated about the benefits of electricity (*e.g.* improved lighting, productivity, schools and health) through awareness campaigns.

Also, productive uses of electricity (*e.g.* powering irrigation pumps; refrigeration; or supporting small businesses such as barber shops, charging stations, welding shops or cold storage) should be encouraged and demonstrated. This includes providing training and support for entrepreneurship.

Community leaders must be involved in outreach efforts to build trust. This will have benefits as communities take ownership of mini-grids and help protect equipment against vandalism and theft.

Reliable and quality service

Unreliable supply from mini-grids can discourage use. It is therefore vital to ensure mini-grids are well designed and well maintained, to provide consistent power.

Reliability of supply can be achieved with high-quality equipment (*e.g.* inverters, batteries and meters) and maintenance by skilled staff (which will minimise breakdowns). In turn these will build community confidence. Warranties and spare parts should be made available; 24/7 customer support for outage reporting and resolution is also critical for better service quality.

Access to productive use appliances

Remote rural communities served by mini-grids have limited access to appliances that can improve livelihoods. To address this challenge, it is advisable to partner with appliance providers for providing affordable, energy-efficient devices (*e.g.* efficient water pumps, refrigerators, light-emitting diodes or grain mills).

Since the appliances can be costly, providing financing options for purchasing them will be beneficial (*e.g.* micro-loans or lease-to-own models). Partnering with micro-finance institutions offering loans for business development would also be a good strategy.

Capacity building and training

Understandably, end users in remote rural communities usually do not have technical knowledge relevant to mini-grids. Capacity building within local communities is a key component of end user support. Capacity building can be through:

- Training local technicians to handle basic repairs and maintenance;
- Educating users on safe electricity practices (*e.g.* avoiding overloading circuits);
- Providing training on productive uses of electricity to help users generate an income; and
- Training users on how to operate and maintain appliances.

Inclusive and gender-sensitive approaches

It is not uncommon for women and marginalised groups to be excluded from decision making or the benefits of electrification. Community consultations and decision-making processes should ensure women's meaningful engagement. Tariffs and payment systems (*e.g.* mobile money platforms) should be designed considering their accessibility to women. Also, appliances that reduce women's domestic workload (*e.g.* electric mills or water pumps) must be promoted.

Monitoring and feedback mechanisms

Another way to support electricity users is to enable them to share their feedback; lack of such support could lead to dissatisfaction. Systems for reporting issues or providing feedback must be set up. Hotlines or mobile applications can be launched. User satisfaction must be monitored and concerns addressed promptly. It is helpful to conduct surveys to understand user needs and preferences.

Ensuring safety and security

Electricity-related accidents or theft can undermine trust in mini-grids. Safety features (*e.g.* circuit breakers and grounding/earthing systems) must be installed in mini-grid systems. Users must be educated on electrical safety practices. Communities receiving electricity for the first time must be trained in the safe use of electrical appliances. Failure to do this could have fatal consequences. Sometimes, and perhaps all too often, thieves and vandals could try to steal or damage mini-grid equipment (solar panels, batteries, *etc.*). Mini-grid infrastructure must be secured against such attempts. Closed-circuit television (CCTV) or similar remote monitoring technologies, including alarm systems, could be used to this end.

Scalable and adaptable solutions

Given that user needs can evolve, especially in communities that have electricity for the first time, mini-grids must be designed with scalability in mind so as to accommodate growth in demand. One option that addresses both scalability and adaptability is a modular system, which can be expanded as needed. The system should be assessed regularly to ensure it meets evolving user needs, and that services can be expanded/adapted as needed.

Other critical considerations

Partnerships and collaboration

Limited resources could hinder support for end users in paying for connections. This challenge can be addressed by partnering with non-governmental organisations, government agencies and private companies to provide additional support, for example, for training, financing or appliances. It is also advisable to collaborate with local organisations to leverage their knowledge as well as networks.

Environmental awareness

The common lack of awareness about the environmental benefits of mini-grids within governments and communities could be a challenge to securing support for developing sustainable renewables-based mini-grids. Educating users on the environmental benefits of renewable energy (*e.g.* reduced kerosene use or diesel emissions) could prove beneficial. Energy-efficient appliances should also be promoted, to reduce energy waste.

Long-term engagement

Often, short-term interventions to expand electricity access are deployed for various reasons, including political expediency to gain votes. Such interventions may not yield sustained benefits. Ongoing engagement with the community must be maintained, to build trust and ensure long-term success. This includes providing continuous support for maintenance, training and capacity building.

Conclusion

Supporting the end users of mini-grids requires a holistic approach that addresses technical, financial, social and educational aspects. By focusing on affordability, reliability, capacity building and community engagement, mini-grid operators can ensure that end users fully benefit from access to electricity, which enhances livelihoods and contributes to sustainable development.

MODULE 2 REFLECTIONS

- *Clear policy and regulations are an essential starting point for the development of sustainable renewable-energy-based mini-grids. For policy and regulations to be effective, supportive institutional frameworks must be established and well resourced, including with a competent and experienced cadre of technicians. Focusing on a particular country, reflect on the effectiveness of the agencies and ministries responsible for rural electrification.*
- *Based on what you have learnt in this module, and again focusing on a country of your choice, are the plans for the arrival of the main grid in regions now served by mini-grids adequate?*
- *How can poor rural communities be supported to increase their ability to pay for mini-grid services?*
- *What are the main barriers to entering the mini-grid market*?

MODULE 2 RECOMMENDED READING

1. *Renewable Mini-Grids Innovation Landscape Brief* (IRENA, 2019)
2. *Renewable Energy and Solar Research Report* (RatedPower, 2025)
3. *Innovation Outlook: Renewable Mini-Grids, Summary for Policy Makers* (IRENA, 2016)
4. *Scaling Up Access to Electricity: Emerging Best Practices for Mini-Grid Regulation* (ESMAP, 2015b)
5. *Policies and Regulations for Renewable Energy Mini-Grids* (IRENA, 2018)

MODULE 2 QUIZ

1. **From the options below, select all key barriers faced by developers seeking to enter the mini-grid market:**
   a. Lack of planning data
   b. Very poor communities
   c. Competition from alternative energy sources
   d. Lack of understanding of benefits of electricity
   e. Gender issues
   f. Land access and use
2. **From the following options, choose one aspect of mini-grids that can take the most time and careful planning:**
   a. Capacity building for mini-grid maintenance
   b. Educating the community about electricity
   c. Poverty reduction through productive uses of electricity
   d. Mini-grid construction
   e. Mini-grid maintenance
3. **Which of the following statements on mini-grid tariffs is/are correct?**
   a. Solar-PV-based mini-grids have higher tariffs than mini-grids based on diesel generation.
   b. Tariffs for all renewable-energy-based mini-grids are the same.
   c. The tariffs for mini-grids are usually lower than for the main grid.
   d. The tariffs for mini-grids are usually higher than for the main grid.
4. **What options are used to address the issue of affordability and ability to pay? Select all that apply:**
   a. Applying the same tariff to all consumers, for fairness
   b. Applying tiered tariffs, with the first units consumed charged at a lower rate
   c. Subsidising tariffs for everyone

5. **Which are the main components of a solar PV mini-grid?**
   a. Solar panels
   b. Inverter
   c. Diesel generator
   d. Wind turbine
   e. Batteries
   f. Biomass plant
6. **What are the key technical specifications for battery energy that can be used in a storage system?**
   a. Frequency of operation
   b. Battery voltage
   c. Capacity in kilowatt hours
   d. Depth of discharge
   e. Days of autonomy
   f. Lifespan
7. **From the list below, select the adverse impacts that mini-grid developers risk facing with grid integration:**
   a. Stranded assets
   b. Loss of revenue
   c. Lower tariffs for consumers
   d. Higher tariffs for consumers
8. **Select ways to mitigate the risks associated with the arrival of the main grid integration:**
   a. Set up a compensation scheme for developers
   b. Plan for the grid integration of generation by harmonising technical standards
   c. Recover all equipment and deploy it elsewhere
   d. Sell the equipment to third parties
   e. All of the above
9. **One way of supporting mini-grid users is to provide quality service. Which of the following actions align with this objective?**
   a. Provide free electricity
   b. Provide 24/7 customer support for reporting and resolving outages
   c. Ensure gender equality in recruitment of maintenance staff
   d. Use high-quality equipment and skilled maintenance staff
   e. Only use one brand of equipment in the mini-grid
10. **Select the main risks of not educating and involving the community during the development and deployment of mini-grids:**
    a. There will be a general lack of awareness about the full benefits of electricity in the community and the mini-grid will be in limited use by the community.
    b. The community will already be aware of productive uses of electricity.
    c. The community will lack knowledge of entrepreneurship using electricity.
    d. There will be trust between the community and the mini-grid developers.
    e. The mini-grid will potentially be at risk of vandalism by the community.

MODULE 3 –
KEY ACTORS AND INSTITUTIONS

RECAP OF MODULE 2

Module 2 focused on mini-grid regulations. Five topics were covered:

- **Market entry,** including barriers to entry, and how they can be addressed.
- **Tariffs.** Key considerations in formulating tariffs for rural, often low-income, communities were presented, with suggested solutions for ensuring affordability while recovering costs.
- **Technical specifications.** Robust technical specifications are important, to ensure that flexible, modular systems can adapt to the evolving needs of communities.
- **What happens when the main grid arrives?** The module outlined ways to address key challenges without putting the mini-grid developer at a disadvantage.
- **Supporting end users.** Is important to raise awareness (and build capacity) in the application of electrical devices/equipment for productive use, as well as safety considerations.

MODULE OBJECTIVES

This is the third module in IRENA's e-learning course on policy and regulatory frameworks for renewable-energy-based mini-grids. This module outlines the key actors and institutions in the development of mini-grids. In particular, it looks at (1) national-level institutions, (2) mechanisms for co-ordination among the actors and institutions and (3) the roles of other actors. By the end of this module, students will have gained a basic understanding of the institutional arrangements behind the development of sustainable mini-grids in rural communities.

MODULE 3 OUTLINE

Building on Module 2, this module discusses the key actors and institutions involved in the development and operation of mini-grids. It consists of three units:

- Unit 1 – National-level institutions
- Unit 2 – Roles of other actors
- Unit 3 – Co-ordination mechanisms

The first unit outlines the national-level institutions necessary for the rural electrification ecosystem to function in a co-ordinated manner. Next, the second unit contains a discussion of the mechanisms for co-ordination among the key institutions. The third unit focuses on the role of other actors in the development and operation of renewables-based mini-grids to ensure they are sustainable in the long term.

UNIT 1 – NATIONAL-LEVEL INSTITUTIONS

Several national-level institutions play a crucial role in the development, regulation and scale-up of mini-grid systems. The following institutions are typically involved in policy making, financing, technical support and infrastructure development.

Ministries of energy or power are typically responsible for formulating national energy policies, including those related to renewable energy and off-grid solutions such as mini-grids. They also oversee the co-ordination of energy projects and ensure that mini-grid systems align with national energy goals.

Regulatory authorities include those at the national and local level. A **national electricity regulatory commission or board** regulates the operation of electricity providers. It ensures that mini-grids meet safety, quality and pricing standards. It often sets tariff structures and determines the rules for the operation of mini-grids in rural or off-grid areas. In some countries, specific **rural electrification agencies** are tasked with regulating renewable energy projects and offering incentives for their development.

National development banks often provide funding or financial instruments specifically to support the promotion of renewable energy development, including mini-grids. They may also facilitate loans or subsidies for the construction and expansion of mini-grid systems.

In some cases, state-owned or private **utility companies** are involved in the design, implementation and management of mini-grids, especially if they are part of the national grid extension strategy.

National universities, research institutes and **energy centres** often play a significant role in technical development, innovation and research related to mini-grid technologies and business models.

National governments often collaborate with **development partners** like the United Nations Development Programme or the World Bank and other multilateral development banks that provide funding, expertise and technical support for mini-grid projects.

Local government bodies and **regional authorities** are responsible for land use, project approvals and ensuring that mini-grid systems meet community needs and environmental standards. They also help in co-ordinating local-level engagement with the communities that mini-grids will serve.

Many mini-grid developers are **private companies**, ranging from local businesses to international firms, which may work under public-private partnerships (PPPs) to develop mini-grid systems.

National standards organisations help define and enforce technical standards for mini-grids, including standards for grid inter-operability, safety measures, performance standards and environmental safeguards. They ensure that mini-grids are integrated seamlessly into the broader energy system.

Community-based organisations and **non-governmental organisations (NGOs)** are especially important constituencies that must be consulted in the development of mini-grids.

Conclusion

The institutions listed above collaborate to create an enabling environment for mini-grid development. They ensure that they help expand access to energy in a sustainable and economically viable manner.

UNIT 2 – ROLE OF OTHER ACTORS

The development, implementation and scale-up of mini-grids involves other players in addition to national-level institutions. These other players operate in a defined geographic or thematic scope and play crucial roles. They often bring unique skills, resources and expertise that complement the work of national and government bodies and help overcome the challenges of providing energy to off-grid communities. Below is an overview of the roles of these key players.

Local communities

Local communities are the end users as well as stakeholders of mini-grid systems. Their engagement and participation are essential for ensuring the success and sustainability of mini-grid projects. End users utilise the electricity generated by mini-grids for various purposes, such as lighting, powering appliances and supporting businesses (whose revenue can in turn be used to pay for the electricity). It is important to gather their feedback on system performance, usage patterns and satisfaction to help the mini-grid reliably meet community needs and expectations. Innovative payment models (*e.g.* prepayment meters) help maintain the financial viability of mini-grids.

Members of the community who are not connected to the mini-grid are still important to engage, since they will also be affected by the mini-grid's presence in their community.

In some cases, communities may co-own or manage mini-grids, especially where community-based organisations or co-operatives are formed to ensure long-term operation.

Private sector companies (mini-grid developers)

Private companies are often the primary developers and operators of mini-grids. They design, finance, build and maintain mini-grid systems. Private companies may specialise in renewable energy technologies like solar, wind or hydro. Their roles can include the following:

- **Development:** Identifying suitable sites, designing mini-grid systems and managing the construction.
- **Operation and maintenance:** Ensuring the system operates effectively over its life cycle and providing ongoing support and repair services.
- **Innovation:** Introducing new technologies and business models to make mini-grids more cost-effective and scalable.
- **Financing:** Raising the necessary capital (both equity and debt) to fund mini-grid projects.

Development partners (international agencies, NGOs)

International development organisations (such as the World Bank; UK Foreign, Commonwealth and Development Office; United Nations Development Programme; and others) and NGOs are instrumental in providing funding, technical assistance and expertise to help overcome the barriers to mini-grid development. Their roles in mini-grid development can include the following:

- **Funding:** Offering grants, low-interest loans or risk guarantees to attract private investment in mini-grid projects.
- **Capacity building:** Supporting the training of local communities, government officials and businesses on mini-grid technologies and management.
- **Policy advocacy:** Assisting governments in designing supportive policies and regulatory frameworks for mini-grid development.
- **Monitoring and evaluation (M&E):** Providing technical assistance to track the performance and impact of mini-grid projects.

Technology providers and equipment suppliers

Technology providers and equipment suppliers provide the equipment, technology and software needed to operate mini-grids. This can include solar panels, batteries, inverters, controllers, meters and energy management systems. Key roles include the following:

- **Equipment supply:** Manufacturing and supplying the hardware needed to build and maintain mini-grid systems.
- **Innovation and research and development:** Developing more efficient, cost-effective and scalable energy solutions and improving mini-grid technology.
- **Integration and system design:** Providing technical solutions that integrate renewable energy sources, storage and management systems into a functional and reliable mini-grid.

Local contractors and service providers

The roles of the local companies or individuals responsible for the construction and installation of mini-grids and their ongoing maintenance include the following:

- **Construction:** Building the infrastructure for mini-grid systems, including installation of renewable energy components, electrical wiring and storage systems.
- **Maintenance:** Providing ongoing operation and maintenance services, including repairs and upgrades to ensure the reliability and longevity of mini-grids.

Consultants and technical advisors

Independent consultants and technical advisory firms play an important role in supporting both public and private sector stakeholders with specialised knowledge. Among other roles, they:

- **Conduct feasibility studies,** including technical, financial and environmental assessments to determine the viability of mini-grid projects in specific locations.
- **Support project design and planning,** providing expertise in system design, optimisation and integration with existing infrastructure (*e.g.* the national grid or other mini-grids).
- **Assist in capacity building,** helping local institutions, operators and government officials develop skills and knowledge.
- **Help monitor and evaluate** the implementation and performance of mini-grid projects.

Academic and research institutions

Universities, energy research centres and think tanks conduct research that can support the growth of the mini-grid sector. They contribute to mini-grid development through the following areas:

- **Technology research:** Innovating new technologies and solutions that can make mini-grids more efficient, affordable and adaptable to local contexts.
- **Policy research:** Conducting studies on the social, economic and environmental impacts of mini-grids and providing recommendations for policy development.
- **Training and education:** Providing educational programmes for energy professionals and offering training on mini-grid technologies and best practices.

Regulatory and standardisation bodies

National and international regulatory bodies and standard-setting organisations ensure that mini-grids meet safety, performance and environmental standards. Their roles include those listed below.

- **Regulation:** Setting and enforcing regulations on mini-grid licensing, pricing and quality of service.
- **Standards development:** Establishing technical standards for mini-grid components, ensuring inter-operability and system reliability.
- **Consumer protection:** Ensuring that mini-grid operators meet acceptable service levels and protect the rights of consumers, including through transparency in pricing and reliability of service.

Local governments

Local governments play a key role in facilitating mini-grid development. They ensure that projects are aligned with local needs and regulations. Among other roles, they are involved in the following areas:

- **Land use and permitting:** Providing necessary approvals for land use, siting of mini-grids and ensuring compliance with environmental regulations.
- **Community engagement:** Ensuring that local communities are involved in the planning and implementation phases and that their needs are considered.
- **Monitoring and oversight:** Ensuring that mini-grid systems are operated in compliance with local laws and that they deliver the expected benefits to the community.

Financial institutions (banks, investors, impact funds)

Financial institutions play a critical role in providing the capital necessary to fund mini-grid projects. They include, among others, commercial banks, impact investors, venture capital firms and development finance institutions. Their contributions include the following:

- **Investment:** Providing debt and equity financing for mini-grid projects or funds that pool resources to invest in mini-grids.
- **Innovative financing models:** Designing innovative financing mechanisms (*e.g.* pay-as-you-go systems) to reduce up-front costs for customers and make mini-grids financially viable.
- **Risk mitigation:** Offering credit guarantees, insurance or other instruments to de-risk investments in mini-grid projects, making them more attractive to investors.

Conclusion

The development of mini-grids involves a range of players, each with a specific role in ensuring projects are a success and also sustainable. From technology suppliers and private developers to financial institutions, local governments and end users, each actor brings essential resources, expertise and support to the process. Collaboration among these stakeholders, along with strong co-ordination and alignment of their individual goals, is crucial for overcoming the challenges and scaling up mini-grid solutions.

UNIT 3 – CO-ORDINATION MECHANISMS

Co-ordination of the key institutions in mini-grid development is essential for ensuring that projects are successfully planned, implemented and maintained. Effective co-ordination helps in streamlining the efforts of various stakeholders, facilitating the flow of resources and avoiding duplicate work. The co-ordination mechanisms typically seen in mini-grid development are outlined below:

- **National steering committees or task forces** bring together representatives from various ministries (*e.g.* energy, finance, environment), regulatory bodies and development partners (including the private sector and NGOs) to oversee the development and implementation of mini-grid policies and projects. They provide high-level co-ordination, decision making and policy direction to ensure that mini-grid projects are aligned with national goals.
- **Inter-ministerial working groups** facilitate co-operation between ministries that have a role in mini-grid development, such as energy, environment, finance and local governments. They address policy issues, co-ordinate funding mechanisms and resolve conflicts between ministries or other actors involved in mini-grid implementation.
- **Regulatory co-ordination bodies**, such as electricity commissions or renewable energy regulatory authorities, often work together to set rules, tariffs and performance standards for mini-grid operators. They may include utility companies and stakeholders from the private sector. These bodies work to ensure that there is clarity on licensing, tariff-setting, technical standards and dispute resolution processes between mini-grid operators, customers and the national grid.
- Mini-grid development often relies on **public-private partnerships (PPPs)** between government institutions and private companies to provide funding, technical expertise and operational know-how. The partnerships include government agencies (energy ministries, local authorities), financial institutions (development banks, national banks) and private sector developers (energy companies, equipment suppliers). They facilitate the joint investment, risk-sharing and resource mobilisation necessary to develop mini-grid infrastructure. PPPs often use incentives like subsidies, tax breaks or guarantees to encourage private sector participation.
- **Sector-specific technical committees or advisory groups** focus on the technical aspects of mini-grid systems, including the selection of technologies, integration with the national grid and environmental concerns. They bring together technical experts from energy ministries, research institutes, universities and independent consultants, who provide technical expertise on mini-grid design, development and operations, ensuring that projects meet national and international standards.
- Many countries rely on international development partners (*e.g.* the World Bank) to provide funding and technical support for mini-grid projects. Co-ordination between these partners ensures that their efforts complement each other and do not overlap. **Development partner co-ordination mechanisms** serve to co-ordinate donor funding, create synergies between projects, share information and track progress towards energy access goals.
- Engaging local communities is essential to the success of mini-grid projects, which often serve off-grid populations in rural or remote areas. **Community stakeholder engagement platform**s bring together local government representatives, community leaders, NGOs and mini-grid developers. They facilitate community consultations, and ensure that local needs and preferences are considered, and establish feedback mechanisms to address concerns related to mini-grid projects.
- **M&E committees** track the progress of mini-grid projects, assessing outcomes against targets such as increased access to electricity, economic development and system reliability. Representatives from government ministries, regulatory bodies, development partners and independent auditors ensure that mini-grid projects meet their objectives, provide reports on performance and make adjustments to policies or projects if necessary.
- In countries with decentralised governance structures, **regional or local co-ordination bodies** may exist to ensure that mini-grid projects are effectively planned and managed at the local level. These bodies bring together regional authorities, local energy committees, mini-grid operators and utility companies. They work to co-ordinate the delivery of energy services in rural or peri-urban areas, ensuring that local needs are addressed, land rights are respected and the community is involved in decision making.

- **Information sharing platforms** such as national energy portals or sector-specific databases enable key institutions to share data on mini-grid performance, best practices, lessons learnt and other valuable insights. These platforms bring together energy ministries, development partners, research organisations and mini-grid developers. They facilitate the flow of information to all stakeholders, enabling informed decision making and reducing the risk of misalignment between institutions involved in mini-grid projects.
- Since mini-grid development requires significant up-front investment, mechanisms that co-ordinate the flow of funding from public and private sources are essential. Development banks, commercial banks, government ministries and private investors may come together to mobilise funds for mini-grid development, explore innovative financing models (such as impact investing) and de-risk investments through guarantees or subsidies.

Conclusion

The successful development and scale-up of mini-grids require well-structured co-ordination among various key national institutions. These co-ordination mechanisms help align the efforts of government ministries, regulatory bodies, development partners, the private sector and local communities to ensure that mini-grid projects are effective, sustainable and provide energy access to underserved populations. Effective co-ordination improves project outcomes, optimises resource utilisation and reduces the risk of project failure.

MODULE 3 REFLECTIONS

- *Focusing on a specific country of your choice, reflect on the issues related to institutional arrangements supportive of mini-grid development and the effectiveness of these arrangements.*
- *User support, especially in remote rural communities, is essential. How, in your view, should social-cultural norms specific to each community be approached in mini-grid development?*

MODULE 3 RECOMMENDED READING

1. *Renewable Mini-Grids Innovation Landscape Brief* (IRENA, 2019)
2. *Renewable Energy and Solar Research Trends Report* (RatedPower, 2025)
3. *Innovation Outlook: Renewable Mini-Grids Summary for Policy Makers* (IRENA, 2016)
4. *Scaling Up Access to Electricity: Emerging Best Practices for Mini-Grid Regulation* (ESMAP, 2015a)
5. *Policies and Regulations for Mini-Grids* (IRENA, 2018)

MODULE 3 QUIZ

1. **Select all institutions that are important to sustainable mini-grid development:**
   a. Regulatory authority
   b. Trade union
   c. Rural electrification agency
   d. Youth organisations
   e. Churches
   f. Local governments
   g. Women's organisations
2. **What is the main role of the national government in mini-grid development?**
   a. Come up with legislation to incentivise mini-grid developers
   b. Define regulations for mini-grids
   c. Develop policy for mini-grids
   d. Issue licenses for mini-grids

3. **Which of the following national entities are not critical in mini-grid development?**
    a. National development banks
    b. Utility companies
    c. Human rights organisations
    d. Research institutions
    e. Private sector companies
    f. National standards organisations

4. **Which of the following is the role of consumers in mini-grids?**
    a. Provide feedback on quality and reliability of service
    b. Outline procedures for integrating mini-grids with the main grid
    c. Balancing the level of government control over mini-grid deployment
    d. Pay for the energy consumed

5. **What is the role of regulators in mini-grid development and deployment?**
    a. Mini-grid licensing
    b. Enforcing quality of service
    c. Standards development
    d. Developing policy
    e. Consumer protection

6. **What is the purpose of PPPs in mini-grid development?**
    a. Provision of funding
    b. Provision of technical expertise
    c. Development of standards
    d. Provision of operational know-how
    e. Development of regulations

7. **Who would you expect to be involved in PPPs?**
    a. Government agencies
    b. Private sector developers
    c. Universities and technical colleges
    d. Equipment suppliers
    e. Workers unions

8. **What are the roles of PPPs?**
    a. Facilitate joint investment
    b. Resource mobilisation necessary to develop mini-grid infrastructure
    c. Policy development
    d. Risk sharing
    e. Developing national electrification plans

9. **Which of the following actors does not have a critical role to play in mini-grid development and deployment**?
    a. Technology providers and equipment suppliers
    b. Local contractors and service providers
    c. Consultants and technical advisors
    d. Academic and research institutions
    e. Regulatory and standardisation bodies
    f. None of the above

10. **What is the role of academic and research institutions in mini-grid development?**
    a. Enacting mini-grid laws
    b. Raising funds for mini-grid development
    c. Technology research
    d. Training and education
    e. Lobbying government for gender equality

MODULE 4 – CREATING AN ECOSYSTEM FOR SUCCESSFUL MINI-GRIDS

RECAP OF MODULE 3

Module 3 outlined three key topics relevant to the development of mini-grids: (1) the roles of national-level institutions and (2) other actors and (3) mechanisms for co-ordination among actors and institutions. It emphasised the need to set up a robust institutional framework to support mini-grid development. The Ministry of Energy sets policy, while the electrification and regulatory authorities ensure fair pricing and adherence to high technical standards. Co-ordination among the key actors is important. Private sector actors, too, can help rural communities gain access to electricity from renewable energy sources.

MODULE 4 OBJECTIVES

This is the fourth module discusses five key topics:

- The key ingredients of successful mini-grid development
- The need for a clear legal and regulatory framework that includes risk management and allocation
- The importance of community engagement, including gender and social inclusion, while respecting social norms
- Capacity building
- Ways to effectively communicate about mini-grid projects to community members

By the end of this module, users should have a sound understanding of the key requirements for creating an ecosystem that supports successful and sustainable mini-grids based on renewable energy sources.

MODULE 4 OUTLINE

This module on creating an ecosystem for successful mini-grids consists of the following five units:

- Unit 1 – What are the key ingredients of successful mini-grid development?
- Unit 2 – A clear legal and regulatory framework that includes risk management
- Unit 3 – Prioritising gender and social inclusion while respecting social norms
- Unit 4 – Capacity building
- Unit 5 – Effectively communicating with local communities

UNIT 1 – WHAT ARE THE KEY INGREDIENTS OF SUCCESSFUL MINI-GRID DEVELOPMENT?

Successful mini-grid development requires a combination of technical, financial, regulatory and community-focused elements. Below are the key ingredients.

Robust technical design

Technology selection for mini-grids is central to their success. Renewable-energy-based mini-grids can utilise solar, wind, hydro, biomass or hybrid systems. The design of mini-grids must consider local resources and energy demand.

Another important consideration in technical design is scalability. It should be possible to scale the selected design and technology systems as demand grows.

A key design consideration is the storage system. This must incorporate reliable battery storage or other solutions to support consistent power supply, especially for solar photovoltaic systems, whose resource is available only during daylight hours.

The last design point is the distribution network, which must be well planned to minimise losses and ensure reliability. In other words, the network must be efficient in the delivery of energy to end users.

Sustainable financial models

A key consideration in the design of mini-grids is financial sustainability. This can mean the success or failure of the system. It is, therefore, critical to devise cost-effective solutions using affordable and durable equipment to reduce capital and operational costs.

Moreover, it is essential to ensure that revenue streams support the financial sustainability of mini-grids. Clear pricing mechanisms and payment systems, for example, pay-as-you-go or tiered tariffs, as discussed in earlier modules, can help achieve this.

Funding and investment are also critical to the success of mini-grids. As much as possible, efforts must be made to secure funding through grants, loans or public-private partnerships (PPPs) to cover up-front costs. Subsidies and incentives provided by government or international entities can be used to make energy affordable for end users.

Supportive regulatory framework

The need for clear policies on mini-grid development was discussed in earlier modules. Policies supporting mini-grid development, including licensing, tariffs and grid inter-connection rules, must be developed.

As part of the regulatory framework, it is helpful to provide incentives for mini-grid developers. Such incentives could include tax breaks or subsidies to attract private sector investment. It is also helpful to standardise processes for mini-grid development. This would require simplified permitting and approval processes to reduce delays and costs.

Community engagement and ownership

The importance of local participation in mini-grid development has been a recurrent theme in the course. It is worth restating that involving community members in planning and decision making throughout the mini-grid development phase is important to ensure the system meets their needs.

It has been emphasised that the long-term sustainability of mini-grids necessitates training local technicians and operators to manage and maintain the system. Plans to implement mini-grids need to factor in capacity building.

The need to educate communities about the benefits and use of mini-grids to drive their adoption has already been discussed but is worth repeating here. Awareness campaigns are, therefore, an essential aspect of the mini-grid development ecosystem.

Social inclusion is another key aspect of mini-grid development. This is to ensure equitable access to electricity for all community members, including women and youth, as well as marginalised groups.

Reliable operation and maintenance

Regular maintenance of mini-grids is essential to ensure they remain reliable in the long term. It goes without saying that maintenance crews must be within reach of mini-grid users, and skilled. Local technicians must be trained to handle routine maintenance and repairs.

There is also a need to monitor mini-grid performance and to proactively address issues. Remote monitoring and data analytics are important in detecting potential issues.

For technicians to properly maintain and repair mini-grids, they need easy access to spare parts. Timely access to spare parts and equipment will minimise system downtime.

Integration with national grids (when the main grid arrives)

Earlier modules discussed the technical and commercial challenges posed by the arrival of the main grid. On the technical front, the importance of developing standards for connecting mini-grids to the national grid, if needed, was emphasised.

It is also important to ensure grid stability when the main grid arrives. The mini-grid must be designed to be able to operate independently or in sync with the main grid, without causing instability.

Environmental and social considerations

Policies and regulations must promote the use of renewable energy sources for mini-grids to minimise environmental impact. This has been a major theme throughout this course.

Land use consideration and the need for mini-grid development permits have been addressed in earlier modules. Land acquisition and environmental permits must be addressed early in the mini-grid planning process.

In addition to the usual environmental impact assessment, social impact assessments must be undertaken. Social impact assessments must evaluate and mitigate any negative social impacts of mini-grid projects. These impacts could vary and could include the exploitation of children or use of child labour and disregard for local social norms.

Data-driven planning

As much as possible, mini-grid planning must be based on robust data. The critical starting point is energy demand assessment. Energy demand must be assessed through detailed studies to understand community energy needs and consumption patterns. Since rural electrification provides new electricity services, demand estimates/projections will be needed, given there is no existing use of electricity.

Once the energy demand is understood, resource mapping must be undertaken. This entails assessing local renewable energy resources, such as solar irradiance, wind speed and water flow, which are required to optimise the mini-grid system design.

Where practical, it is worth undertaking pilot projects. Pilot projects test small-scale systems to gather data and refine designs before scaling them up. It is acknowledged that this is not always possible, however.

Partnerships and collaboration

The important role of PPPs was emphasised in earlier modules. Within the mini-grid development ecosystem, collaboration with governments, non-governmental organisations and private companies to share risks and resources is desirable and often essential for success.

Long-term vision

Taking a long-term perspective in mini-grid planning is important. Developers must plan for future technological advancements and changes in energy demand (*i.e.* plans must be adaptable). Exit strategies need to be developed, should the need arise – for example, if the main grid arrives or if the mini-grid is no longer viable (*e.g.* if the demand is not what was anticipated, and it is no longer financially possible to operate the mini-grid). Developers and regulators must collaborate to develop clear plans for handover to communities or integration with the main grid if needed, or decommission mini-grids as the case may be.

Conclusion

Addressing these key requirements can ensure that mini-grid projects provide reliable, affordable and sustainable energy access to underserved communities while minimising risks.

UNIT 2 – A CLEAR LEGAL AND REGULATORY FRAMEWORK THAT INCLUDES RISK MANAGEMENT

A legal and regulatory framework for mini-grid development is vital to ensuring projects are sustainable, can be scaled and are financially viable. The framework provides clarity for developers, investors and communities, while also addressing risks and ensuring equitable outcomes. Below are the key components of such a framework, including risk management and allocation.

Legal framework

Clear ownership and licensing rules

It is important, in the first instance, to clearly define who can own and operate mini-grids. This can be private companies, communities, co-operatives or even the government through appropriate ownership vehicles.

Additionally, licensing requirements and procedures for mini-grid developers must be established. This is to provide clarity on the processes developers must follow.

Land use and rights

All renewable energy projects must be constructed on land. Access to land is therefore a critical pre-condition for any mini-grid project. Land acquisition processes for mini-grid infrastructure must be clarified. In some jurisdictions, land could be communal or even contested. All issues related to land must be addressed.

Environmental compliance

Nowadays, practically all projects are required to adhere to environmental standards. Developers must ensure compliance with set environmental standards and requirements for mini-grid projects. It is advisable and highly recommended to mandate environmental impact assessments where necessary, even in cases where legislation is weak.

Grid interconnection and off-take agreements

Mini-grids are, by definition, not connected to the national grid. However, it is prudent to provide safeguards up-front for the possibility of grid integration. Rules for connecting mini-grids to the national grid must be defined, therefore. This would consider national standards and grid codes, ensuring that the mini-grid is designed to be compliant with them. It is also important to establish terms for selling excess power to the main grid should this become possible.

Regulatory framework

Tariff setting and revenue models

Setting tariffs is a complex process and often must consider conflicting objectives. For example, the ability of tariffs to reflect costs might conflict with affordability. It is nevertheless important to permit the requirement of cost-reflective revenues to ensure financial sustainability. Furthermore, mechanisms to subsidise tariffs for low-income consumers may be needed. In other words, some flexibility must be allowed for developers to set tariffs based on local conditions.

Quality and performance standards

It has already been emphasised in this course that the reliability of mini-grids is important to engender trust with the user community. This requires setting technical standards for equipment, installation and operation and mandating regular reporting and monitoring of mini-grids' performance.

Simplified approval processes

To support the rapid development of mini-grids and reduce delays and costs, permitting and licensing processes need to be streamlined. Ideally, it is recommended to create a "one-stop shop" for mini-grid approvals.

Incentives for developers and investors

It is also helpful to offer tax breaks, grants or subsidies to attract investment. Another critical issue is financial risk for developers. To mitigate this risk, the provision of guarantees or risk-sharing mechanisms should be considered.

Risk management and allocation

The single most important barrier to mini-grid development by the private sector is risk. There are several risks associated with mini-grid development. These are discussed below, with suggestions on how they can be allocated and managed.

Political and regulatory risks can be significant and must be addressed up-front. Political risks typically manifest in policy changes or regulatory uncertainty. These risks can be mitigated through long-term contracts or guarantees. Also, robust mechanisms for conflict resolution between developers and regulators must be established.

Financial risks: Without clear financial risk allocation, it is almost impossible to reach financial close for any project, including mini-grid projects. Financial risk must be allocated among developers, investors and governments, for example, through PPPs. Use of blended finance models can reduce the cost of capital.

Operational risks usually arise when maintenance is poor or absent. It is therefore important to ensure developers have access to technical expertise and training is provided for local operators. It is also recommended to require developers to maintain contingency plans for equipment failure or natural disasters. A stock of readily available spare parts is one way to guarantee speedy resolution of system failures.

Market risks: Low demand or non-payment of electricity bills by consumers are two major market risks. They can be addressed by conducting thorough demand assessments and implementing pay-as-you-go systems or tiered tariffs and providing subsidies or grants to ensure affordability for end users.

Currency and exchange rate risks can be significant in unstable economies. This is a major concern and consideration for foreign investors. To mitigate this risk for foreign investors, it is recommended to offer mechanisms to hedge against currency fluctuations.

Force majeure risks: It is always advisable to include force majeure clauses in mini-grid contracts to address risks from natural disasters, political instability or other unforeseen events.

Community and social considerations

Mini-grids serve sizeable communities whose interests must be safeguarded. Usually this is accomplished through regulatory measures. Where mini-grid regulations are absent, rules for consumer protection against unfair pricing or poor service should be established. The rules must also ensure (1) transparency in billing and service delivery and (2) equitable access by mandating that mini-grids serve all community members, including marginalised groups.

Integration with national energy policies

Mini-grid development must support national energy access and renewable energy targets. It must align with rural electrification plans, and be integrated in broader rural electrification strategies to avoid duplication of efforts, especially with targets for extending the national grid.

Monitoring and enforcement

It is recommended to establish a dedicated regulatory body to oversee mini-grid development and operations where such a body does not exist. Where a regulatory body exists, its mandate must be extended to the regulation of mini-grids. The regulatory oversight must include performance monitoring through mandatory regular reporting on the technical, financial and social performance of mini-grids. Where performance fails to meet regulatory standards or contractual obligations, penalties for non-compliance must be enforced.

International best practices and adaptation

Learning from successful models and adapting regulatory frameworks from countries with successful mini-grid programmes (*e.g.* Kenya, the United Republic of Tanzania, Nigeria and India) is important, therefore, to incorporate global best practices for renewable energy and mini-grid development.

Conclusion

By establishing a comprehensive legal and regulatory framework that addresses the above aspects, governments can create an enabling environment for mini-grid development. Regulation should also define or facilitate business models that are truly sustainable.

This framework should balance the interests of developers, investors and communities while enabling effective risk management and allocation.

UNIT 3 – PRIORITISING GENDER AND SOCIAL INCLUSION WHILE RESPECTING SOCIAL NORMS

Community engagement, including gender and social inclusion, is a cornerstone of successful mini-grid development. It ensures that projects are socially acceptable, equitable and sustainable and also respect local norms and traditions. Below are key strategies for effective community engagement, with a focus on gender and social inclusion.

Inclusive planning and decision making

The starting point for inclusive planning and decision making is to undertake a stakeholder mapping exercise. Stakeholder mapping involves identifying all relevant stakeholders, including women, youth, marginalised groups, traditional leaders and local businesses.

After undertaking stakeholder mapping, it is important to involve community stakeholders in the planning, design and implementation of mini-grid projects through consultations, workshops and focus group discussions.

Local community leaders are a key stakeholder group. It is important to work with traditional leaders and local authorities to gain their support and ensure alignment with community priorities.

Gender inclusion

The system design of mini-grids, especially for deployment in remote rural communities, too often fails to consider women's specific needs. Mini-grid systems must be designed to meet the energy needs of women (*e.g.* lighting for household chores), support outdoor lighting, which can increase women's sense of safety and security, and provide power for small businesses or energy for healthcare facilities.

It is important to actively involve women in decision-making processes and leadership roles within mini-grid projects. To ensure that women can participate effectively, it necessary to create spaces where women feel comfortable expressing their needs and concerns.

Women must be economically empowered. They must be provided training and opportunities to participate in the mini-grid value chain, for example, as technicians, entrepreneurs or operators. It is also important to support women-led businesses that can benefit from reliable energy access.

Women's participation in mini-grid development and indeed in other activities typically associated with men is often hindered by cultural norms. Awareness of cultural norms potentially limiting female participation and finding ways to work within them, or gradually move away from them, is important.

Social inclusion

Mini-grid planning and deployment must ensure that vulnerable groups – for example, low-income households, people with disabilities and ethnic minorities – are included in the projects and benefit from access to energy. This requires identifying these groups during stakeholder mapping.

To ensure equitable benefits and decision making for the community, it is worth exploring co-operative or community-owned mini-grid models. However, there are many issues that must be addressed satisfactorily for such models to be sustained. For example, the community would need help increasing its technical and administrative capacity to own and operate the mini-grids.

Respecting social norms

For mini-grids to gain acceptance and remain sustainable in the long term, they must operate within the boundaries of local cultural and social norms. Mini-grid developers should strive to understand and respect local customs, traditions and social structures and adapt engagement strategies to align with cultural norms while promoting inclusivity.

Conflict resolution

Conflicts can arise in the process of developing or operating mini-grids (*e.g.* land disputes and resource allocation). Dialogue and mediation are recommended to address such conflicts between the community and mini-grid developers.

It is important, during stakeholder mapping, to identify and work with respected community members who can advocate for projects and help bridge cultural gaps.

Capacity building and awareness

Capacity building is essential for the sustainability of mini-grids. Training on the benefits of mini-grids, energy efficiency and safe use of electricity is therefore important. It must be offered to local community members, especially women and youth, as well as to people with disabilities as appropriate.

As mentioned earlier, launching awareness campaigns on mini-grid projects and their benefits is important. Local media, community meetings and demonstrations can be leveraged for raising awareness.

Behavioural change

The power supplied by renewables-based mini-grids tends to be more expensive than that supplied by the main grid. The consumption of the power supplied by mini-grids should be carefully managed, therefore. Mini-grid developers, supported by local community champions, should promote energy-efficient practices and productive uses of energy to maximise benefits.

Monitoring and feedback

Considering community feedback is important to ensure user satisfaction with the services provided by the mini-grid. Channels for community members to provide feedback and report issues should be established. Feedback channels can include suggestion boxes, hotlines and community meetings.

It is recommended to conduct regular assessments to evaluate projects' impact on different social groups and adjust strategies as needed. This would help ensure that mini-grids address the needs of different community members.

There should be complete transparency on all aspects of mini-grids with the community, to avoid speculation, disinformation or misinformation about the mini-grids. Information on project progress, costs and benefits, for example, can help ensure transparency.

Long-term engagement

It is a good practice to form community committees to oversee mini-grids' operation and maintenance; this ensures long-term ownership and accountability. Through such committees, it would be possible to maintain ongoing communication with the community to address emerging issues and adapt to changing needs.

Examples of best practices

The lessons learnt from mini-grid projects should be recorded and used to inform future mini-grid developments in other communities. Developers can learn from projects that have effectively integrated gender and social inclusion, such as:

- **Kenya's solar mini-grids,** which focused on women's economic empowerment through energy access (World Bank, 2017a); and
- **The United Republic of Tanzania's community-based models,** which engaged local communities in ownership and management.

Of course, good practice strategies must be tailored to the specific cultural, social and economic context of each community.

Conclusion

By prioritising community engagement, gender inclusion and social equity, mini-grid developers can build trust, ensure project sustainability and maximise the positive impact of energy access on communities. Respecting social norms while promoting inclusiveness is key to achieving these goals.

UNIT 4 – CAPACITY BUILDING

Capacity building is a critical component of the successful development and operation of mini-grids. It ensures that local communities, technicians and stakeholders have the skills, knowledge and resources to effectively manage and maintain mini-grid systems. Below are key strategies for capacity building in mini-grid development and operation.

Training for local technicians and operators

Technical skill development: Hands-on training in the installation, operation and maintenance of mini-grid systems, including solar photovoltaic, batteries and inverters, as well as distribution networks, is essential. The training must include troubleshooting and repair techniques for common technical issues.

Safety training: Safety is among the most important considerations in installing and operating any electrical power system. Mini-grids are no different. Technicians must be educated on electrical safety standards and practices to prevent accidents and ensure operational safety. They must be trained on how to render equipment safe to work with and its safe return to service. It is also important to assess site risk before work is undertaken.

Ongoing support: It is recommended to establish mentorship programmes or partner with experienced technicians to provide continuous learning opportunities for local technicians. This is especially important when training local technicians with no prior knowledge of or experience in managing and maintaining mini-grids.

Community awareness and education

Energy literacy: When planning mini-grids for deployment in remote rural communities, community members must be educated on the benefits of mini-grids, energy efficiency and safe electricity use. This must be undertaken before the mini-grid is commissioned. The training should also incorporate energy-saving practices and responsible consumption to optimise system performance.

Productive uses of energy: It is also important to train local entrepreneurs and businesses on how to use electricity for income-generating activities (*e.g.* agro-processing, refrigeration or small-scale manufacturing). Even households can use electricity for generating income (*e.g.* electric sewing machines or phone charging services).

Institutional capacity building

Local governance structures: To ensure the smooth operation of mini-grids, community leaders and committees must be trained to oversee mini-grids' operations, manage finances and resolve disputes.

Financial management: Training in budgeting, tariff collection and financial reporting is critical to ensure the sustainability of mini-grids.

Regulatory compliance: It is important to educate stakeholders on relevant regulations, licensing requirements and environmental standards. In turn they will be able to confidently respond to issues that may arise during various stages of mini-grid development.

Partnerships with educational institutions

Curriculum development: For the long-term sustainability of mini-grids, it is essential to ensure there is a pipeline of trained staff at all levels. Joint development of courses on renewable energy and mini-grid systems with local technical schools or universities can be beneficial in this regard.

Internships and apprenticeships: It is also a good practice to offer practical training opportunities for students to gain experience in installing and maintaining mini-grids. Internships and apprenticeships are the two commonly used models.

Research and innovation: To ensure continuous improvement in mini-grid development and operation, research and innovation should be supported. Partnering with academic institutions, which can conduct continuous research on improving mini-grid technologies and operations, can be beneficial in this regard.

Gender-inclusive capacity building

Women must be encouraged to participate in technical training programmes and leadership roles. To enable women to participate effectively, they must be provided with childcare assistance or offered flexible training schedules to accommodate their responsibilities.

Women entrepreneurs should be supported in developing businesses that rely on mini-grid electricity. Women-run businesses relying on mini-grids should also be targeted for capacity building in entrepreneurship.

The role of women in mini-grid development must be highlighted through awareness campaigns. The campaigns should focus on the role of women in access to energy and promote gender equality in mini-grid projects.

Digital tools and remote support

Remote monitoring and diagnostics are an efficient and effective way of ensuring the system is well maintained and issues can be resolved timely. Operators should therefore be trained in the use of digital tools for monitoring system performance and identifying issues remotely.

Training can be undertaken online to minimise cost. It is, therefore, recommended to develop e-learning modules for continuous education and skill development. Students must be supported in accessing the courses through, for example, laptop computers or smart phones, as well as through access to the internet.

It is desirable and recommended, where feasible, to establish helplines or chatbots to provide real-time assistance to local operators. Such solutions save time and resources.

Knowledge sharing and networking

Knowledge sharing and networking are effective and efficient ways for communities to learn from each other (*i.e.* peer learning). This requires creating an environment where communities or mini-grid operators can share best practices and lessons learnt. This can include exchange visits between communities served by mini-grids.

Organising workshops and/or conferences to bring together stakeholders, including developers, policy makers and community representatives, is an effective way of maintaining a vibrant mini-grid ecosystem. It is important to document successful mini-grid projects and disseminate findings to inform future initiatives.

Long-term sustainability

The challenges in mini-grid ownership can be significant. Communities should therefore be supported to build their capacity to assume full ownership of mini-grid systems, including financial and operational management. Formalising them through certification would incentivise community members to partake in capacity-building initiatives.

Other models of mini-grid ownership and management include being managed by private entities, by faith-based institutions and by the government.

The local maintenance team must be trained in developing and implementing routine maintenance schedules to ensure the longevity of mini-grid systems. The maintenance undertaken must be documented properly with robust record keeping.

Training for local operators should also include inventory management and procurement of spare parts as needed.

Monitoring and evaluation (M&E)

Any system that is introduced to support the proper functioning of the mini-grid, requires M&E. Below is a summary of the elements of a typical M&E framework that communities should be trained on.

- Stakeholders should be trained in monitoring system performance and the collection of data on energy generation, consumption and revenue.
- Channels should be established for community members to provide input and report issues. Examples of these channels have been provided earlier in this course.
- The community should be trained in the use of monitoring data to identify areas for improvement, and training programmes should be adapted accordingly.

Scale-up and replication

To ensure the long-term sustainability of the mini-grid and scale it up, it is a good practice to adopt the following strategies:

- After training the first cadre of technicians (*e.g.* by experts recruited by the mini-grid developer), a cadre of local trainers who can train others in developing and operating mini-grids should be identified. This is important for the long-term sustainability of the mini-grid, since staff turnover is always anticipated.
- Developing reusable training resources that can be adapted for different contexts is an efficient solution.
- Capacity building should also be extended to policy makers. This is to create an enabling environment for mini-grid development.

Conclusion

By investing in capacity building, mini-grid projects can empower local communities, ensure the long-term sustainability of energy systems and create economic opportunities. This approach not only improves technical skills but also fosters ownership, inclusivity and resilience.

UNIT 5 – EFFECTIVELY COMMUNICATING WITH THE COMMUNITY

Effective communication with the community is essential for the success of a mini-grid project. It builds trust, ensures transparency and fosters community ownership and support. Below are strategies for communicating effectively with the community throughout the project life cycle.

Pre-project phase: Building awareness and trust

To execute successful mini-grid projects, it is essential to build awareness of the project and trust with the community. This can be done through:

- **Convening community meetings**. The developer or promoter of a mini-grid project must organise open forums to introduce the project, explain its benefits and address any concerns that arise. For effective communication, it is important to use local languages and culturally appropriate communication methods. This means developers must be supported by local people who understand and can communicate in the local language and are familiar with the cultural norms.
- **Stakeholder mapping.** Some prior engagement with the community, to identify community leaders, influencers and important groups (*e.g.* women, youth and the elderly), is essential. This is to ensure inclusive and effective communication.
- **Information campaigns.** Campaigns can be launched to inform the community about mini-grid projects. Using posters, flyers, radio broadcasts and social media to share information about the project can be highly effective. Transparency in the dissemination of information is a must. This means clearly explaining the goals of the project, the timeline and potential impacts, both positive and negative.

Planning and design phases: Engaging the community

Community engagement during the planning and design phases is another key step in the development of mini-grids. This can be accomplished through:

- **Participatory workshops.** Developers or promoters must organise workshops within the community, to involve community members in discussions on system design, location and energy needs. Including the community at the design stage minimises the chances of getting things wrong. During the workshops and community meetings, visual aids such as maps, diagrams and models should be used to help community members understand the project layout and components. Adequate time should be allocated for asking and answering questions.
- **Feedback mechanisms.** Building trust and confidence in mini-grid projects requires providing mechanisms for community members to share their input and concerns. Channels for community feedback (*e.g.* suggestion boxes and hotlines) should be established.

Implementation phase: Keeping the community informed

The implementation phase is extremely important. The community must be kept informed of project progress. This can be done by providing frequent progress reports through community meetings, newsletters or local media. Community members or their representatives should be invited to visit project sites to see the work in progress. Providing a prompt response to questions, complaints or concerns, if any, with clear explanations is vital.

Operational phase: Ensuring ongoing engagement

The operational phase is crucial, and, therefore, appropriate mechanisms must be established to ensure long-term reliability and sustainability of the mini-grid. Key elements include:

- **User training.** Before the mini-grid is commissioned, community members must be educated, via workshops, on how to use the mini-grid system safely and efficiently. The education will minimise potential misuse or abuse of the mini-grid, thereby reducing incidences of system failures and accidents.
- **Customer service.** A local office or hotline for billing inquiries, technical support and feedback must be set up. This is vital in establishing trust and confidence in the newly commissioned system, especially in the early stages, when teething issues with the mini-grid and associated systems are anticipated.
- **Community committees.** It is useful and recommended to establish a committee to represent the community's interests and facilitate communication with the project team. This will ensure all concerns of the community are timely addressed.

M&E phase: Sharing results

Once the mini-grid is operational, the performance of the system must be monitored and evaluated. The performance results should be shared with the community or its leadership, including through:

- **Performance reports**. Data on energy generation, energy consumption and revenue should be shared with the community. In this way, suspicion and speculation on any aspects of the mini-grids' performance are eliminated.
- **Success stories.** It is important to highlight how the mini-grid has improved lives in the community (*e.g.* through new businesses, better healthcare or improved education outcomes for children in the community). Sharing success stories will help the community remain invested in the mini-grid's well-being.
- **Lessons learnt.** While sharing success stories is important, it is equally important to discuss the challenges faced in operating the mini-grid and how they were addressed. This will ensure that the lessons learnt inform how to handle similar challenges. This transparent way of working builds trust.
- **Building long-term relationships.** To create an ecosystem that supports the long-term sustainability of mini-grids, open lines of communication with the community must be maintained even after projects are operational. This includes organising events to celebrate project achievements and thanking the community for their support. It is especially important to demonstrate to the community that their views on mini-grid development and operation are valued. Adopting community input to improve communication strategies and project outcomes is a clear way of demonstrating this. Building long-term relationships with the community served by the mini-grid engenders a sense of community ownership, which is vital for long-term sustainability.
- **Tools and channels for effective communication.** There are several tools that can be deployed to ensure effective communication with the beneficiaries of mini-grids during the development and operation phases. Examples of communication channels include local media such as radio, TV and newspapers, which can reach a wide audience. In addition, digital platforms including social media, websites and SMS can be used for communicating updates and announcements. Videos, demonstrations and role-playing can be used to explain complex concepts. These visual and interactive methods can be effective, especially in communities that might be receiving electricity in their homes for the first time. Engaging respected community members to act as ambassadors for projects or local champions can complement these efforts.

- **Strategies for inclusive communication.** To build long-term relationships with the community using the tools and methods discussed above, it is important to adopt inclusive communication strategies. The three key strategies are (1) using gender-sensitive approaches to ensure women are included in communication efforts and their specific energy needs are addressed; (2) targeted outreach that includes vulnerable or under-represented groups, for example, low-income households and people with disabilities; and (3) respecting local customs and traditions in all communication efforts.

Conclusion

By prioritising clear, inclusive and culturally sensitive communication, mini-grid developers can build strong relationships with communities, ensure project success and create lasting positive impacts.

MODULE 4 REFLECTIONS

- *Based on what has been presented in this module and considering any country of your choice, reflect on key issues that this country's mini-grid development ecosystem clearly needs to focus on more.*
- *In a remote rural community receiving electricity for the first time, what are the main issues to consider when preparing community members for the arrival of mini-grids?*
- *What in your experience are the main causes of mini-grid failures and how can they be mitigated during the planning phase?*

MODULE 4 RECOMMENDED READING

1. *Renewable Mini-Grids Innovation Landscape Brief* (IRENA, 2019)
2. *Powercorner/ENGIE – Ketumbeine Mini-Grid of 16 kW of PV Panels, 45 kWh of Lithium Batteries and a Back-Up Genset (Tanzania)* (Patel, 2016)
3. *Hybrid Mini-Grids for Rural Electrification: Lessons Learned* (ARE, 2011)
4. *Green Mini-Grids in Sub-Saharan Africa: Analysis of Barriers to Growth and the Potential Role of the African Development Bank in Supporting the Sector* (Energy 4 Impact and INENSUS, 2016)
5. *International Off-Grid Renewable Energy Conference (IOREC) 2012: Key Findings and Recommendations* (IRENA, 2013)
6. *Renewable Power Generation Costs in 2024* (IRENA, 2025)
7. *Off-Grid Renewable Energy Systems: Status and Methodological Issues* (IRENA, 2015)

MODULE 4 QUIZ

1. **Which of the following do you consider to be key requirements for successful mini-grid development?**
   a. Robust technical design
   b. Use of wind and solar power
   c. Sustainable financial models
   d. Employing female engineers
   e. Using Homer software in the design of the mini-grid
   f. Environmental and social considerations

2. **Which of the following would you consider as effective channels for providing constructive feedback on mini-grid performance?**
   a. Suggestion boxes
   b. Social media
   c. Internet
   d. Radio
   e. Hotlines
   f. Newspapers

3. **Which of the following are the important phases of mini-grid development?**
   a. Building awareness and trust
   b. Planning and design
   c. Implementation
   d. Operations
   e. Appreciation
   f. All of the above

4. **Which of the following should be covered by the legal framework for mini-grid development?**
   a. Clear ownership and licensing rules
   b. Feedback mechanisms
   c. Land use and rights
   d. Gender inclusion quarters
   e. Environmental compliance
   f. Grid inter-connection and off-take agreements
   g. Planning tools

5. **In mini-grid development and operation, which of the following are the reasons for partnering with educational institutions?**
   a. Promoting higher education
   b. Curriculum development
   c. Internships and apprenticeships for students
   d. Research and innovation
   e. Social media presence
   f. Enforcing standards

6. **From the following list, which groups within the community should be identified in stakeholder mapping for mini-grid development?**
   a. Community leaders
   b. Teachers
   c. Tradesmen
   d. Influencers
   e. Women
   f. Highly educated people

7. **Why is it important to build institutional capacity in local governance structures in mini-grid development and operation?**
   a. Because community leaders and committees oversee mini-grid operations
   b. So that operators can earn good salaries
   c. To ensure youth employment
   d. To ensure competent management of finances
   e. To preside over resolving disputes

8. **Which are key areas to be covered when engaging communities to be supplied with electricity from a mini-grid for the first time?**
   a. Benefits of mini-grids
   b. Energy efficiency
   c. Safe electricity usage
   d. None of the above

9. **How can a developer ensure they respect social norms in areas where they plan to deploy a mini-grid?**
   a. Engage the local police to learn about social norms
   b. Use common sense
   c. Identify and work with respected community members to learn about cultural sensitivity
   d. Understand and respect local customs, traditions and social structures and adapt engagement strategies to align with cultural norms while promoting inclusivity
   e. Use dialogue and mediation to resolve conflicts
   f. Work with youth

10. **Which of the following would you consider as a good practice to ensure the long-term sustainability and scale-up of mini-grids?**
   a. Training of trainers
   b. Training women in operating the mini-grid
   c. Training youth in maintaining the mini-grid
   d. Only using computers to maintain records
   e. Standardising training materials

MODULE 5 – FROM THE DEVELOPMENT OF POLICIES AND REGULATIONS TO IMPLEMENTATION

RECAP OF MODULE 4

Module 4 discussed key requirements in the creation of an ecosystem for successful mini-grid development. The module focused on five aspects, as summarised below.

- **Key ingredients for successful mini-grid development:** We learnt that successful mini-grid development requires robust technical design, a sustainable financial model, a supportive regulatory framework, community engagement and ownership, reliable operation and maintenance, integration with national grids (when the grid arrives), environmental and social considerations, data-driven planning, partnerships and collaboration, and having a long-term vision.
- **Need for a clear legal and regulatory framework including risk management and allocation:** Beyond integration with national energy policies, monitoring and enforcement, it is important to benchmark international best practices and adaptation.
- **Community engagement:** We learnt that by prioritising community engagement, gender inclusion and social equity, mini-grid developers can build trust, ensure project sustainability and maximise the positive impact of energy access on communities. Achieving these goals requires respecting social norms while promoting inclusiveness.
- **Capacity building:** We learnt that by investing in capacity building, mini-grid projects can empower local communities, ensure energy systems are sustainable in the long term and create economic opportunities. Capacity building not only enhances technical skills but also fosters ownership, inclusivity and resilience.
- **Effectively communicating about mini-grid projects to the community:** A key takeaway from this unit was that prioritising clear, inclusive and culturally sensitive communication can enable mini-grid developers to build strong relationships with communities, ensure the success of projects and create lasting positive impacts.

Module 4 provided a good background and context for this module, which covers aspects of implementation.

MODULE 5 OBJECTIVES

This is the fifth and final module of IRENA's e-learning course on renewables-based mini-grid policy and regulatory frameworks. The module explores the implementation mechanisms for successful and sustainable mini-grids that utilise renewable energy technologies. All the knowledge that students gained in the previous modules is synthesised into required implementation mechanisms for mini-grids. By the end of this module, students will understand the process of implementing mini-grids in alignment with relevant policies and regulations.

MODULE 5 OUTLINE

This module on the implementation mechanisms for mini-grid regulations consists of four units:

- Unit 1 – A designated government rural electrification entity
- Unit 2 – Professional project management
- Unit 3 – Use of qualified mini-grid developers and adherence to standards
- Unit 4 – Monitoring and evaluation (M&E)

The first unit discusses the need to designate a government entity responsible for rural electrification given that mini-grids are mostly implemented in remote rural communities. The second unit addresses the imperative to use professional project managers in the execution of mini-grid projects. The third unit discusses the importance of using reputable and qualified mini-grid developers and of enforcing strict adherence to standards in the construction of mini-grids. The fourth unit presents M&E for mini-grid development, including after the commissioning of the system.

UNIT 1 – A DESIGNATED GOVERNMENT RURAL ELECTRIFICATION ENTITY

Effective development and scaling of mini-grid projects, especially in underserved or off-grid areas, requires establishing a designated government rural electrification entity (GREE), which can play a central role in co-ordinating, regulating and supporting mini-grid development so that equitable and sustainable energy access is achieved. Below are the key reasons why a GREE is essential for mini-grid development.

Centralised co-ordination and planning

A GREE should ideally develop and implement a comprehensive rural electrification plan that integrates mini-grids with other energy solutions (*e.g.* solar home systems and grid extensions). It should also undertake resource mapping by conducting detailed assessments of energy resources, demand and socio-economic conditions to identify optimal locations for mini-grids.

The GREE can also ensure co-ordination among stakeholders (*e.g.* government agencies, private developers, non-governmental organisations) to prevent overlapping projects and ensure efficient resource allocation.

Policy and regulatory support

Policies, regulations and standards for mini-grid development must be established. These include licensing, tariffs and technical requirements for a successful mini-grid development.

To attract private investment, incentives are important. These can include financial incentives (*e.g.* subsidies and tax breaks), as well as risk mitigation mechanisms. Also, permitting and licensing processes must be simplified to reduce delays and costs for developers.

Finance mobilisation and support

Throughout this course, it has been emphasised that financing is critical for mini-grid projects. Funding must be mobilised from government budgets, international donors and development banks. It is important to consider using blended financing models that combine public and private funding.

To ensure the energy produced by mini-grids is affordable, support can be provided through targeted subsidies to ensure energy access for low-income households.

Technical assistance and capacity building

Guidelines and standards are critical for mini-grid development. It is therefore important to develop technical standards for mini-grid design, installation and operation to ensure quality and reliability.

Developers must offer training for local technicians, operators and community members to build technical and managerial capacity.

The rural electrification authority must facilitate the exchange of best practices and lessons learnt among stakeholders. Knowledge sharing reduces the repetition of mistakes, thereby optimising the use of scarce resources.

Community engagement and social inclusion

Involving stakeholders in mini-grid development is essential and has been discussed throughout this course. Communities must be actively involved in planning and decision-making processes surrounding mini-grid development. Another important consideration is gender and social equity. Inclusive energy access must be promoted by addressing the needs of women, marginalised groups and vulnerable populations.

Earlier in the module, we also discussed launching awareness campaigns to educate communities about the benefits of mini-grids and encourage the productive use of energy.

Monitoring, evaluation and accountability

To ensure that mini-grids achieve their objectives, their performance must be tracked by monitoring the technical, financial and social performance of mini-grid projects.

Accountability in mini-grid development requires creating an environment of transparency and effective reporting. This can be achieved by maintaining open communication with stakeholders and providing regular update on project progress.

The socio-economic and environmental impacts of the mini-grid must be evaluated to inform future projects.

Integration with national energy goals

It is important to ensure that mini-grid development aligns with national energy access and renewable energy targets. As discussed in earlier modules, it is important to develop policies and technical standards for integrating mini-grids with the national grid, if the national grid arrives. Successful mini-grid projects can be used as models for scaling up rural electrification efforts.

Risk management and conflict resolution

Risk mitigation in mini-grid development has been discussed before. It is nevertheless worth reiterating that political, financial and operational risks must be addressed through clear policies, guarantees and support mechanisms. Also, there must be mechanisms for developers, communities and other stakeholders to resolve conflicts.

Promoting innovation and sustainability

For mini-grids to be sustainable in the long term, innovation must be encouraged. Innovation in mini-grid technologies, business models and financing must be supported through appropriate mechanisms.

At the same time, attention must be paid to environmental sustainability. This can be accomplished by promoting the use of renewable energy sources and ensuring compliance with environmental regulations.

It is important to emphasise that mini-grids must be maintained regularly. Strategies for the sustainable operation and maintenance of mini-grid systems, including ongoing funding for operation and maintenance, are therefore crucial.

Global examples

It is important to learn from countries with effective GREEs, including:

- **Kenya,** where the Rural Electrification Authority (REA) has played a key role in expanding energy access through mini-grids and solar home systems (The Role of Sense of Ownership in Rural Community Mini-Grid Management: Qualitative Case Study from Tanzania [Ngoti, 2024]);
- **India,** where the Ministry of New and Renewable Energy has supported mini-grid development through subsidies and policy frameworks;
- **United Republic of Tanzania,** where the Rural Energy Agency has facilitated mini-grid development through funding and regulatory support; and
- **Zambia,** which established the Rural Electrification Authority, funded through a levy on electricity bills.

Conclusion

The creation of an enabling environment for mini-grid development necessitates a designated GREE. By facilitating the centralised co-ordination of electrification modes, policy support, financial mobilisation and technical assistance, a GREE can drive the expansion of energy access in rural areas, improve the quality of life for communities and contribute to national development goals. Its role in fostering collaboration among stakeholders, ensuring inclusivity and promoting sustainability makes it a cornerstone of successful rural electrification efforts.

UNIT 2 – PROFESSIONAL PROJECT MANAGEMENT

Timely delivery of mini-grids within budget, and to the desired quality standards, requires project management in the implementation of mini-grid projects. Effective project management minimises risks, maximises efficiency and ensures that mini-grid systems are sustainable in the long term. Below are the key reasons project management is essential for mini-grids' development.

Planning and co-ordination

The development of a comprehensive plan for managing mini-grid projects is an important first step in the development and operation of mini-grids. A detailed project plan outlining timeline, budgets, resource requirements and deliverables should be developed and used as a guide to assess progress of project implementation.

Another critical success factor in the implementation of mini-grid projects is stakeholder co-ordination. The promoter, which is often the rural electrification authority, must facilitate collaboration among government agencies, private developers, communities and other stakeholders.

The mini-grid development plan must include a risk matrix. This entails identifying potential risks (*e.g.* technical, financial and regulatory risks) and the development of mitigation strategies.

Efficient resource allocation

Budget management is a key aspect of managing mini-grid projects. The project manager must ensure that financial resources are used efficiently and transparently, to avoid cost overruns. This includes optimal allocation of human, technical and material resources and their effective use to maximise productivity.

A critical aspect of project management is procurement. Procurement of equipment and services must be managed effectively and efficiently to ensure quality, cost-effectiveness and timeliness.

Timely implementation

Timely completion of projects is important because it saves money and inspires confidence. Therefore, once a project plan is developed, progress must be monitored against the timeline and delays must be addressed promptly. Setting and tracking key milestones helps ensure projects stay on track. It is important to adjust project plans as needed, to respond to unforeseen challenges or changes in project scope.

Quality assurance

In the deployment of mini-grids, their design, installation and operation must adhere to established technical standards. Once installed, system performance must be regularly monitored to ensure reliability and efficiency, and that the system adhere to regulatory requirements and environmental standards.

Financial sustainability

During project implementation, including the operating phase, the project manager must monitor and control project costs to ensure financial viability on an ongoing basis. Also, strategies for revenue generation, such as tariff collection and productive use of energy, must be developed and implemented. Another key imperative is ensuring proper co-ordination of funding. This requires judicious management of relationships with funders and ensuring that financial reporting requirements are met.

Risk management and problem solving

It is important to be proactive in risk identification. The project manager must anticipate potential challenges, such as technical failures or community resistance, and develop contingency plans to deal with risks.

Conflicts, whenever they arise among stakeholders during project implementation, should, ideally, be addressed through mediation and negotiation.

Also, the project manager must promptly handle crises if they arise during the implementation of the mini-grid. Any emergencies (*e.g.* natural disasters or system failures) should be dealt with swiftly and effectively.

Key project management tools and techniques

The use of project management software significantly improves project management. Software such as Microsoft Project, Trello or Asana, which help track tasks, timelines and resources, are in common use and should be considered. Use of Gantt charts to visualise project schedules and dependencies is recommended. A useful project management technique is the use of risk registers to document and monitor risks throughout the project life cycle.

Conclusion

Effective project management is essential for the successful development, implementation and operation of mini-grid systems. It ensures that mini-grid projects are delivered on time, within budget and to the desired quality standards and that the needs of communities and stakeholders are also addressed. By adopting best practices in project management, mini-grid developers can maximise the impact of their projects, ensure long-term sustainability of mini-grid systems and contribute to the achievement of universal energy access goals.

UNIT 3 – USE OF QUALIFIED MINI-GRID DEVELOPERS AND ADHERENCE TO STANDARDS

The success, reliability and sustainability of mini-grid projects necessitate using qualified and reputable mini-grid developers and enforcing strict adherence to standards. These help build trust among stakeholders; minimise risks; and ensure that mini-grid systems achieve technical, financial and social objectives. Below are the key reasons and strategies for implementing these practices.

Why use qualified and reputable developers?

Technical expertise. Reputable developers have the experience and knowledge to design, install and operate mini-grid systems that are efficient, reliable and tailored to local conditions. It is the responsibility of the procurement entity to ensure that solicitation documents clearly state the required experience of the developer, not only in terms of technical expertise but also experience in similar circumstances with traceable references.

Quality assurance. Qualified developers adhere to international and national standards, ensuring that equipment and installations are of high quality. It is, nevertheless, still important to verify the performance of past mini-grid projects implemented by a developer.

Financial viability. Experienced developers are more likely to implement sustainable business models, ensuring projects are financially viable in the long term.

Risk mitigation. Using experienced developers reduces the risk of project failure considerably. Reputable developers have a track record of reducing the risk of delays, cost overruns or failures in delivering projects. Again, this must be verified by reviewing past projects implemented by a developer.

Community trust. Working with trusted and experienced developers fosters confidence among communities and stakeholders. This facilitates smoother project implementation.

Why enforce strict adherence to standards?

The delivery of sustainable mini-grids necessitates enforcing strict adherence to standards. Below are the principal benefits of this strategy:

- **System reliability.** Adherence to technical standards ensures that mini-grid systems are safe, durable and capable of meeting energy demand. In other words, system design and delivery complying with standards guarantees system reliability.
- **Interoperability.** Mini-grid systems must be future-proofed by using standardised systems, which are easier to integrate with other energy solutions (*e.g.* connecting to the national grids when they appear). Systems that adhere to standards are also easier to scale up in the future.
- **Consumer protection.** Adherence to standards has significant benefits for consumers as it protects them against substandard and potentially dangerous systems. Standards ensure that users receive reliable and affordable energy services and protect them from exploitative practices.
- **Environmental compliance.** Environmental impact assessment and associated mitigation plans are prerequisites for licensing mini-grids and sourcing concessional financing. During construction, environmental standards must be enforced to minimise the ecological impact of mini-grid projects. Environmental standards can be complemented by also enforcing social safeguards to protect the community against exploitation during the construction and operation of mini-grids. These safeguards are part of the World Bank's financing requirements.
- **Regulatory compliance.** Qualified and experienced developers are more likely to adhere to national and international regulations. This is important to avoid legal issues and ensures eligibility for incentives or subsidies.

Strategies for enforcing strict adherence to standards

Below are some strategies for ensuring strict adherence to standards:

- **Clear technical standards.** It is important to specify or develop (where they do not exist) and communicate detailed technical standards covering:
  - system design, specifing system capacity, voltage levels and redundancy (or system security/ reliability criteria);
  - equipment quality, for example, for solar panels, batteries and inverters;
  - installation and commissioning processes; and
  - the use of national or international standards, such as the International Electrotechnical Commission or Institute of Electrical and Electronics Engineers, as reference points.
- **Third-party inspection.** Independent experts should be engaged to inspect systems before commissioning and certify that they meet the required standards. For this, often an "owner's engineer" is engaged, who will act on behalf of the client throughout project execution.
- **Regular audits and monitoring.** All mini-grid projects must continue to comply with standards throughout their life. It is, therefore, essential that mini-grid systems are periodically audited, to ensure ongoing compliance with standards.
- **Certification of equipment.** Requiring developers and equipment suppliers to obtain certifications from recognised bodies (*e.g.* the International Electrotechnical Commission, Underwriters Laboratories or local regulatory agencies) is an effective way to ensure mini-grid components adhere to recognised standards.
- **Penalties for non-compliance.** Some developers are tempted to avoid compliance with standards, for example, due to the cost associated with them. A robust regime for exacting penalties for non-compliance must be developed. Penalties for noncompliant developers, which should include fines, contract termination or blacklisting, must be strictly enforced.
- **Capacity building.** Assisting developers and local technicians with training and resources to understand and implement standards can help support their enforcement. Where possible, it is recommended to use certified technicians for installing, operating and maintaining mini-grids.

Strategies for selecting qualified and reputable developers

Selecting the developer is one of the important phases of mini-grid development. The key steps in this process are summarised below:

- **Pre-qualification process.** Pre-qualification of potential bidders is a common and standard approach. Pre-qualification makes it possible to shortlist only qualified developers, which are then invited to submit full bids. The first step in pre-qualification is to establish clear criteria for pre-qualifying developers, such as:
  - proven experience in mini-grid development;
  - financial stability and capacity to deliver projects;
  - technical expertise and access to quality equipment; and
  - positive references from previous projects.
- **Competitive bidding.** After shortlisting pre-qualified developers, it is equally important to use transparent and competitive bidding to select developers. This process must ensure fairness and value for money. Scoring systems must be clear to all bidders and the bid assessment panel or committee.
- **Due diligence.** Thorough background checks must be conducted for all preferred bidders selected through the competitive process. This should include, wherever possible, site visits to previous projects and consultations with past clients.
- **Performance-based contracts.** Contracting is the next most critical phase of the developer selection process. Performance-based contracts, which tie payments to the achievement of specific milestones or performance metrics thereby ensuring accountability, are recommended.

Examples of best practices

- **Kenya:** The Rural Electrification Authority pre-qualifies developers and enforces strict technical standards, resulting in high-quality mini-grid projects.
- **United Republic of Tanzania:** The Tanzania Rural Energy Agency requires developers to comply with national standards and conducts regular inspections to ensure compliance.
- **India:** The Ministry of New and Renewable Energy provides subsidies only to developers that meet specified technical and performance standards.

Conclusion

The success of mini-grid projects necessitates using qualified and reputable developers and enforcing strict adherence to standards. These practices ensure that systems are reliable, sustainable and aligned with community needs, and also attract investment and foster trust among stakeholders. By implementing robust selection processes, clear standards and effective monitoring mechanisms, governments and project implementers can maximise the impact of mini-grids and accelerate progress towards universal energy access.

UNIT 4 – MONITORING AND EVALUATION

M&E is a critical component of developing, operating and maintaining mini-grids. It ensures that projects achieve their intended objectives, deliver value to communities and operate sustainably over the long term. A robust M&E framework helps identify successes, challenges and areas for improvement. It enables data-driven decision making and accountability. Below are the key aspects of M&E for mini-grid development.

Objectives of M&E

The main objectives of M&E for projects include:

- **Tracking progress.** Progress tracking, including monitoring mini-grid project implementation against planned timelines, budgets and deliverables, is key.
- **Assessing performance.** This entails evaluation of the technical, financial and social performance of mini-grid systems.
- **Ensuring accountability.** This requires providing transparency to all stakeholders, including funders, governments and communities.
- **Informing decision making.** The data gathered are used to yield insights, which improve project design, implementation and operation.
- **Demonstrating impact.** This requires measuring the socio-economic and environmental benefits of mini-grid projects.

Key performance indicators (KPIs)

KPIs for mini-grid projects include the following.

- **Technical performance,** which includes measuring and recording:
  - energy generation (kilowatt hours/day or month);
  - system uptime and reliability (percentage of time the system is operational);
  - energy losses in distribution (percentage); and
  - battery storage performance (capacity, life cycle).
- **Financial performance,** which involves collecting:
  - the rate of revenue collection (percentage of billed amounts collected);
  - the costs of operation and maintenance (as a percentage of revenue); and
  - cost recovery and profitability.

Social impact

The social impact of a mini-grid on the community can be assessed by counting the number of households and businesses connected to the mini-grid. It is also assessed through improvement in quality of life, for example, provision of lighting, improvement in education (studying at night) and improvement in health outcomes (safe storage of medicines and attending to patients at night). Other important social impacts are the job creation and local economic development that the mini-grid enables.

Environmental impact

The environmental impact of renewables-based mini-grids can be measured through the reduction in greenhouse gas emissions (tons of carbon dioxide avoided) by the displacement of fossil-fuel-based energy sources, mainly diesel generators. Where the mini-grid enables Tier 4 or 5 energy access, switching to electric cooking from charcoal can also have a significant environmental impact. It is, therefore, also important to monitor cooking habits in the community.

Community engagement

Throughout this course, community engagement has been highlighted as essential in the development of mini-grids. Therefore, the level of community participation in project planning and operation must be monitored (*e.g.* the number and nature of committees established and their effectiveness). The level of community participation can be measured through the level of satisfaction among users.

Data collection methods

Performance monitoring requires data to be collected to support the development and computation of the necessary metrics. Below are data collection methods that can be used to support M&E activities:

- **Remote monitoring systems** must be incorporated in the mini-grid system design. As much as possible, Internet of Things–enabled devices can be used to collect real-time data on energy generation, consumption and system performance, as outlined earlier.
- **Geographic information system (GIS)** tools are used to map mini-grid locations and analyse spatial data for planning and evaluation for mini-grids.
- **Data analytics software** can be used to analyse and visualise data. Examples of good tools include Microsoft Excel, Tableau and Power BI.
- **Mobile data collection apps.** Smartphone-compatible apps, for example, KoBoToolbox (a free, open-source platform or SurveyCTO (a paid platform offering more robust features), are common for efficiently collecting field data.
- **Surveys and interviews.** The common method of collecting information on community satisfaction is to conduct surveys and interviews with community members, operators and stakeholders to gather qualitative data. Well-designed questionnaires are also an effective method of collecting feedback on system performance.
- **Field visits** by technical auditors to perform on-site inspections to verify data and assess the physical condition of infrastructure are essential. These visits must be conducted by independent technical auditors. The prospect of technical audit visits could be a strong incentive for mini-grid operators to maintain the system to high standards.
- **Financial records:** It has been emphasised that financial viability is among the most important success factors for mini-grids. Therefore, the finances of the mini-grid must be monitored. This requires analysing financial statements, billing records and revenue collection reports. This can be through external auditors.
- **Social impact assessments** can be used to monitor and measure the social impact of mini-grids. They may be informed by focus group discussions and case studies of socio-economic impacts. Case studies can focus on selected uses, for example, agri-business or commerce (increased trading hours, refrigeration of perishables, *etc.*).

Monitoring framework

A well-designed monitoring framework should consist of the following elements:

- **Baseline data.** Before project implementation, it is important to collect baseline data in all areas that will be subject to M&E for a project. This will enable the measurement of the changes and impacts of the mini-grid.
- **Regular reporting.** A schedule for regular reporting of key M&E metrics should be established. The reporting could, for example, be monthly or quarterly.
- **Real-time dashboards.** In today's digital age, using digital tools for real-time reporting could be very effective. A typical example is using digital dashboards to visualise data and track performance in real time. This should be considered at the project conception and design stages.
- **Third-party audits.** As already mentioned above, it is important to provide a framework for mini-grid

developers and operators to have an incentive to adhere to standards. Technical and non-technical audits of mini-grid development and operation by independent auditors to verify data and assess compliance with standards could provide this incentive.

Evaluation framework

An effective evaluation framework should include the following key elements:

- A **formative evaluation** should be conducted during implementation, with the purpose of making projects more effective and informing future decisions. It entails the identification of challenges and addressing them in real time.
- A **summative evaluation** considers the overall effectiveness or outcome/impact of a mini-grid project, and it is typically conducted at the end of a project. This is a very important process as it speaks to the extent to which the community's needs have been addressed.
- An **impact evaluation** focuses on measuring the long-term socio-economic and environmental outcomes of a mini-grid. This covers the areas mentioned earlier.
- A **cost-benefit analysis** is very important because it compares project costs with benefits to determine economic viability. Economic viability has been a recurring theme in this course, and it underpins the long-term sustainability of a mini-grid.

Stakeholder involvement

It is a good practice to involve community members in data collection and evaluation to ensure their perspectives are captured. Community involvement also contributes to increasing ownership of projects.

To ensure full ownership of mini-grid projects, it is recommended to establish committees with representatives from government, developers, funders and communities to oversee M&E activities.

Transparency is the best way to build trust and accountability, through sharing M&E results with stakeholders. For mini-grids to be viable in the long term, there must be trust with and a sense of project ownership by the community.

Challenges and solutions

Below is a summary of some of the main challenges faced in implementing M&E, as well as suggested solutions:

- **Data quality.** Accurate and reliable data are essential for planning, and can be collected through training and using standardised tools. The data should be verified by third parties.
- **Resource constraints.** Due to competing needs, the resources required to achieve the desired outcomes in most projects tend to be limited. Considering M&E has a critical role in the long-term sustainability of mini-grids, sufficient budget and human resources must be allocated for M&E activities.
- **Continuous improvement.** One of the objectives of M&E for mini-grid projects is to engender a culture of continuous improvement. To achieve this objective, it necessary to provide feedback loops that utilise M&E findings to refine project design, implementation and operation. It is also important to apply the lessons learnt from pilot projects to scale up mini-grid initiatives. Finally, M&E data can be used to inform policy development and advocate for supportive regulatory frameworks.

Conclusion

A robust M&E framework is essential for the success of mini-grid projects. It ensures that systems are technically sound, financially viable and socially impactful and also provides proof of accountability and transparency to stakeholders. By collecting and analysing data, engaging communities and using insights for continuous improvement, M&E helps maximise the benefits of mini-grids and accelerate progress towards universal energy access. The role of government entities in the procurement, development and enforcement of standards in this process is very important.

MODULE 5 REFLECTIONS

- *In your experience or observation, what are the most critical factors that should be considered in developing a mini-grid implementation framework?*
- *What in your view would be the most important consideration in engaging the community in various phases of mini-grid development, from planning through to implementation?*

MODULE 5 RECOMMENDED READING

1. *Environmental and Social Framework Video* (World Bank, 2017b)
2. *Renewable Mini-Grids Innovation Landscape Brief* (IRENA, 2019)
3. *Powercorner/ENGIE – Ketumbeine Mini-Grid of 16 kW of PV Panels, 45 kWh of Lithium Batteries and a Back-Up Genset (Tanzania)* (Patel, 2016)
4. *Hybrid Mini-Grids for Rural Electrification: Lessons Learned* (ARE, 2011)
5. *Green Mini-Grids in Sub-Saharan Africa: Analysis of Barriers to Growth and the Potential Role of the African Development Bank in Supporting the Sector* (Energy 4 Impact *et al.*, 2016)
6. *International Off-Grid Renewable Energy Conference (IOREC 2012): Key Findings and Recommendations* (IRENA, 2013)
7. *Off-Grid Renewable Energy Systems: Status and Methodological Issues* (IRENA, 2015)

MODULE 5 QUIZ

1. **Which of the following functions should fall under a rural electrification authority?**
   a. Constructing mini-grids
   b. Policy and regulatory support
   c. Mini-grid project management
   d. Financial mobilisation and support
   e. Technical assistance and capacity building
   f. Developing rural electrification policies
   g. All of the above

2. **Community engagement and social inclusion are critical in mini-grid development. Which of the following are aspects of social inclusion?**
   a. Promoting higher education for technicians
   b. Active involvement of community in planning and decision-making processes
   c. Campaigning for productive use of energy
   d. Promoting inclusive energy access by addressing the needs of women, marginalised groups and vulnerable populations

3. **Which of the following would you recommend as strategies for selecting qualified and reputable developers?**
   a. Pre-qualifying potential bidders
   b. Conducting due diligence on selected developers
   c. Only use local developers
   d. Make use of international developers
   e. Use competitive bidding to select developers
   f. Favour contractors led by older men

4. **Monitoring and evaluation are important in mini-grid development. Which of the following are elements of the evaluation framework?**
   a. Formative evaluation
   b. Impact evaluation
   c. Measuring energy consumption
   d. Summative evaluation
   e. Promoting energy for productive use

5. **Which of the following data collection methods are best suited for rural communities?**
    a. Data collection with mobile phone–compatible apps
    b. Field visits
    c. Speaking to youth
    d. Surveys and interviews
    e. Speaking only to community leaders
    f. None of the above

6. **On which aspects of mini-grid development should technical standards be strictly enforced?**
    a. Mini-grid equipment
    b. Installation and commissioning of the mini-grid
    c. Cleanliness of installation
    d. System design
    e. Batteries and solar panels
    f. Inverters

7. **Which of the following are key performance indicators for mini-grids?**
    a. Energy generation (kilowatt hours/day or month)
    b. System uptime and reliability (percentage of time the system is operational)
    c. Completion time for the project
    d. Energy losses in distribution (percentage)
    e. Battery storage performance (capacity, life cycle)
    f. None of the above

8. **Why is it advisable to use qualified and reputable mini-grid developers?**
    a. They are likely to know the local community.
    b. They have the experience and knowledge to design, install and operate mini-grids.
    c. They adhere to international and national standards.
    d. Experienced developers charge lower fees.
    e. Using experienced developers reduces the risk of project failure.

9. **From the following list, select the strategies for enforcing strict adherence to standards:**
    a. Enforcing a strict regime of equipment cleanliness
    b. Regular audits and monitoring
    c. Penalties for non-compliance
    d. Installing fire protection equipment
    e. Training youth on data collection

10. **Which project management tools and techniques would you use in mini-grid development?**
    a. Microsoft Project
    b. Gantt charts
    c. Oracle database
    d. Geographical information system (GIS)
    e. Keeping handwritten notes

STUDY ANNEXES

1. *Study of Major Solar Energy Mini-Grid Initiatives in Zambia* (Kapole *et al.*, 2023)
2. *Project Appraisal Document on a Proposed Credit to the Republic of Kenya for an Off-Grid Solar Access Project for Underserved Counties* (World Bank, 2017)
3. *Project Appraisal Document on a Proposed Credit to the Federal Republic of Nigeria for the Nigeria Electrification Project* (World Bank, 2018)
4. *The Role of Sense of Ownership in Rural Community Mini-Grid Management: Qualitative Case Study from Tanzania* (Ngoti, 2024)

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