Introduction to Renewable Energy Systems for Electrification

Amy Rose, NREL
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Dushanbe, Tajikistan
NREL at a Glance

1,700 Employees, plus more than 400 early-career researchers and visiting scientists

World-class facilities, renowned technology experts

nearly 750 Partnerships with industry, academia, and government

Campus operates as a living laboratory

$872M annually National economic impact

National economic impact $872M annually

$872M annually

$872M annually
Rural Electrification Planning and Goals

Levels of Electrification

Why Wind and Solar

Rural Electrification and Resilience

Case Studies
A difficult & universal challenge

Source: BPEI, ALLEVIATING FUEL POVERTY IN THE EU
Rural electrification planning

**Objective:** Provide electricity services at affordable prices and with an acceptable quality of service

**Outcome:** The resulting plan identifies the supply technology for each group of consumers and an appropriate business model to provide that service

**Open Issues:**
What level of service should be provided?
What is an acceptable quality of service?
How should we define affordability?
Is this the right starting point?

Solar home system

Source: Lighting Global

Low-cost grid extension

Source: IFC World Bank, 2012

Grid-compatible microgrid

Source: TARA Urja, India
Planning must start by assessing energy needs

“People do not want electricity or oil, nor such economic abstractions as ‘residential services’, but rather comfortable rooms, light vehicular motion, food, tables, and other real things.”

Amory Lovins, 1976
Understanding electricity needs

Possible demand profiles for different domestic electricity needs

- Basic lighting (CFL)/cell phone charging

- Lighting, heating, cooling, electric cooking

- Lighting, heating, cooling, electric cooking, home appliances
Discussion 1: Electricity Needs in Tajikistan

• In rural Tajikistan, what are the energy needs for
  - Education
  - Health
  - Street lighting
  - Community centers/public spaces
  - Communication
  - Household
  - Economic drivers

• What resources are currently used to meet these needs?
Discussion 2: Electricity Access in Tajikistan

• How easy is it to access energy resources?
  – In Dushanbe
  – In other cities
  – In rural areas

• How much do consumers spend to meet their energy needs?
  – In Dushanbe
  – In other cities
  – In rural areas

• What are the preferred energy resources?
Choose technologies to deliver energy services

<table>
<thead>
<tr>
<th>Electricity service</th>
<th>Possible supply technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ multi-bulb lighting, air circulation, TV</td>
<td>+ low power appliances (water heater, rice cooker)</td>
</tr>
<tr>
<td>+ med power appliances (refrigeration, mechanical loads)</td>
<td>+ high power appliances (electric cooking, space heating)</td>
</tr>
<tr>
<td>Solar lanterns DC standalone systems</td>
<td>AC standalone systems</td>
</tr>
</tbody>
</table>

Technology choice should enable a path to move up the “energy ladder”
Factors in evaluating potential technologies

- **Culture**: accommodate values and concepts of local cultures
- **Affordability**: capital, running, and maintenance costs
- **Operation/Maintenance**: utility operators, trained technicians & spare parts for repairs
- **Physical robustness**: suitable for local weather, environmental and infrastructure conditions
- **Other basic needs**: consider access to and needs for other basic infrastructure (water, sanitation, education, health)
Levels of Electrification
Level 1: Stand Alone Lighting and Charging

- Applications
  - Lighting
  - Cellphone charging
- Users
  - Residential
  - Generally used in very remote, low income areas
- Design
  - Power generation (most often solar)
  - Battery storage
  - Power electronics (charge controllers)
- Pros
  - Simple, mature technology
  - Minimal maintenance
  - Affordable
- Cons
  - Very limited power supply

Source: Greenlight Planet Sunking 400
Level 2: Stand Alone Home Systems

- **Applications**
  - Lighting and small appliances
  - Cellphone charging
  - Radios
  - Communication towers

- **Users**
  - Residential and small commercial/community facilities
  - Generally used in areas with no feasible grid extension
  - Low income areas

- **Design**
  - Power generation (solar, wind, micro-hydro, diesel)
  - Battery storage
  - Power electronics (inverters/rectifiers, charge controllers, energy management systems)
  - Can be DC or AC

- **Pros**
  - Can be modularly increased in size as energy demand increases
  - Can power multiple devices
  - Affordable

- **Cons**
  - Requires increasing levels of operator training and/or outside maintenance
    - More components = more opportunities for failure

Source: Greenlight Planet Sunking Home 120
Level 3: Isolated Microgrids

• Applications
  – Community power in remote locations with no feasible grid extension

• Users
  – Communities or industrial facilities

• Design
  – Power generation is often from more than one energy source (e.g. solar + diesel)
  – Battery storage and/or Thermal storage
  – Power electronics (inverters/rectifiers, charge controllers, energy management systems)

• Pros
  – Generation is flexible to energy demand changes
  – Powers entire communities
  – Greater levels of energy access than standalone systems

• Cons
  – Technically challenging
  – Requires extensive operator training
  – High capital costs

Level 4: Grid-Operable Microgrids

- **Applications**
  - Supplement grid power
  - Resilience and redundancy in outages
- **Users**
  - Communities
  - Industrial users
  - Emergency centers (e.g. hospitals, military bases)
- **Design**
  - Power generation (solar, wind, micro-hydro, diesel)
  - Battery storage (lithium ion)
  - Power electronics (inverters/rectifiers, charge controllers, energy management systems)
- **Pros**
  - Increase power reliability and resilience
  - Offers flexibility to both the customer and the utility through demand response
- **Cons**
  - Sophisticated design requires significant operator training and high levels of coordination between customers and utilities

Why Wind and Solar for Electrification
RE VS Diesel

**On-site resource**
- Utilizes local resource with no reliance on outside imports
- Low operating costs
- Varying levels of complexity and maintenance
- Increasingly cost competitive
- Modular nature allows flexibility in siting

**Imported fuel**
- Historically used for remote power
- High operating costs
- Reliance on imported fuel
- Complex maintenance
- Must be located with fuel source
Reality: Most microgrids have multiple generation technologies

- Typically a mix of diesel, RE, and batteries
- Reduces cost of diesel imports while supplying year-round power
- In colder climates, diesel waste heat is utilized by community
Solar PV

- **Pros**
  - Universal resource
  - Mature, low maintenance technology
  - Average production is well understood
  - Low cost

- **Challenges**
  - Highly subject to shading and clouds
  - Can be challenging to integrate with older distribution systems (both grid and microgrid)
  - Lower production rates in winter when power is most needed
Wind

• Pros
  – Works year round
  – Mature technology
  – Low cost

• Challenges
  – Highly subject to micrositing
  – Can be challenging to integrate with older distribution systems (both grid and microgrid)
Remote Energy Case Studies
Solar and Wind
Experiences from Remote US Locations

- Alaska has over 200 remote power systems that provide electricity to off-grid homes
  - All utilize diesel to some extent
  - Many have hybrid systems that incorporate solar, wind, and hydro
- There are approximately 18,000 homes in the US with no access to electricity

Diesel power house in Rampart, Alaska, USA
Chaninik Wind Group
Alaska

- Four villages ranging in size from 200-350 people
- Remote power houses require expensive fuel shipped in for electricity generation ($1.77/liter)
- Residents rely on shipped in fuel oil for heat ($1.87/liter)
- No roads to villages
  - Access by planes year round and barges in the summer

Source; Dennis Meiners, Intelligent Engineering Systems
Chaninik Wind Group
Alaska

• Villages joined together to share resources
• Oversized the wind generation with respect to electricity
• Excess wind is stored in two ways
  – Batteries to provide grid services
  – Thermal units in residential homes

Source: NREL
Chaninik Wind Group
Alaska Challenges

• Remote nature of villages made installation technically challenging and costly
• Lack of local capacity to maintain systems
• Electric grids needed significant updating to accommodate systems
• Financing

Source: NREL
Chaninik Wind Group
Alaska Benefits

• Significant fuel savings
• Reduced cost of electricity
• Reduced cost of heating
• Increased reliability of power
• 5-10 local jobs in each community

Source: NREL
Navajo Nation

- Approximately 15,000 homes lack access to electricity
- Local utility has programs for grid extension and stand-alone systems
- Rates vary between on and off-grid customers but are designed to be affordable

Source: US Department of Energy
Navajo Nation

- Grid extension to clustered communities as funds allow
  - Communities are prioritized in the utility master plan
- Stand alone systems are provided to remote homes
  - Power is provided for lights, limited refrigeration, radio, television, and water pumping
  - Power stations are typically solar, wind, and batteries

Source; SEIA https://www.seia.org/blog/grid-solar-filling-void-power-deprived
Thank you

www.nrel.gov

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