Simulation and optimization of renewable energy hybrid power system for Semonkong, Lesotho

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A Case for Mini-grids

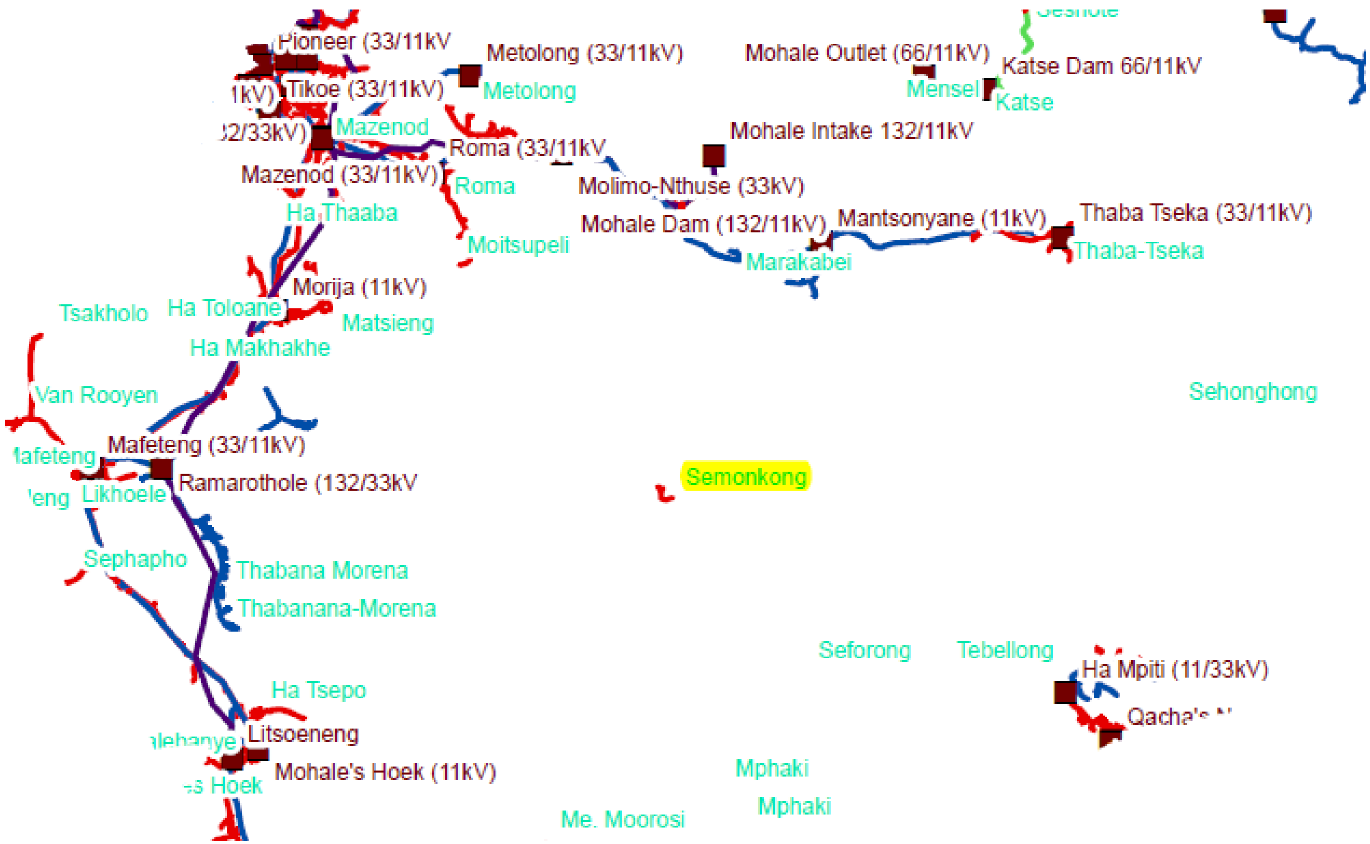
- Around 600 million people in Sub-Saharan Africa have no access to electricity
  - In Lesotho, around 60% (1.1 million) do not have access to electricity

- Majority of people without access are in remote, isolated, rural, mountainous and sparsely-populated areas
  - Grid extension to such areas is technically challenging, prohibitively expensive and financially unviable
  - This hampers social and economic developments due to insufficient provision of much-needed power

- Hence, decentralized hybrid mini-grids become handy solutions for provision of electricity in homes, schools, clinics, police-stations, local businesses, etc.
  - Cost-effective and more preferable if they are based on locally-available renewable energy resources (solar, wind and/or hydro)

Semonkong Overview (1)

- One such rural and isolated town in Lesotho is Semonkong, at least 70 km away from grid



- Currently supplied with a hydro (180 kW) /diesel genset (500 kVA) hybrid, run by the national utility

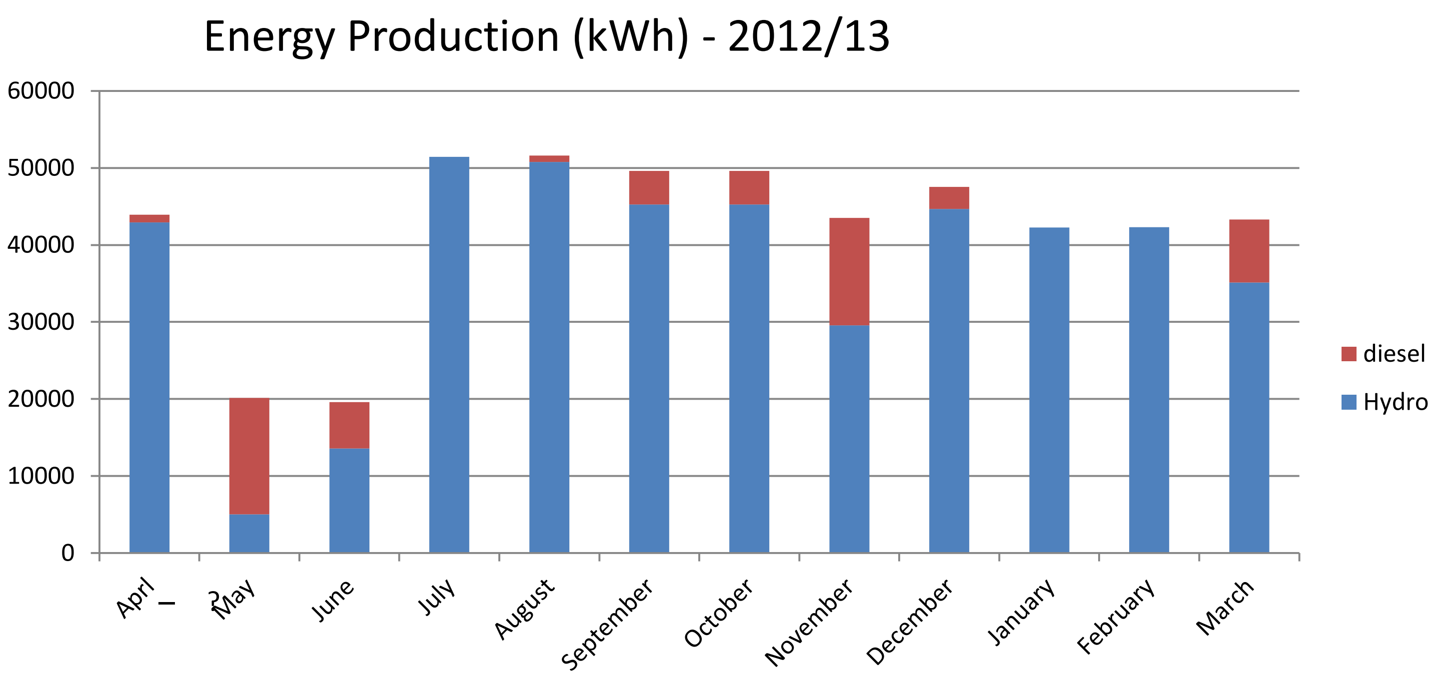
Semonkong Overview (2)

- Due to the low economic activity, challenging mountainous terrain and difficult access for transmission lines, grid extension to Semonkong in the short to medium term will come at a very high cost

- However, the current hydro-diesel hybrid is not cost-effective either
  - It's highly subsidized and increases the overall cost for all consumers

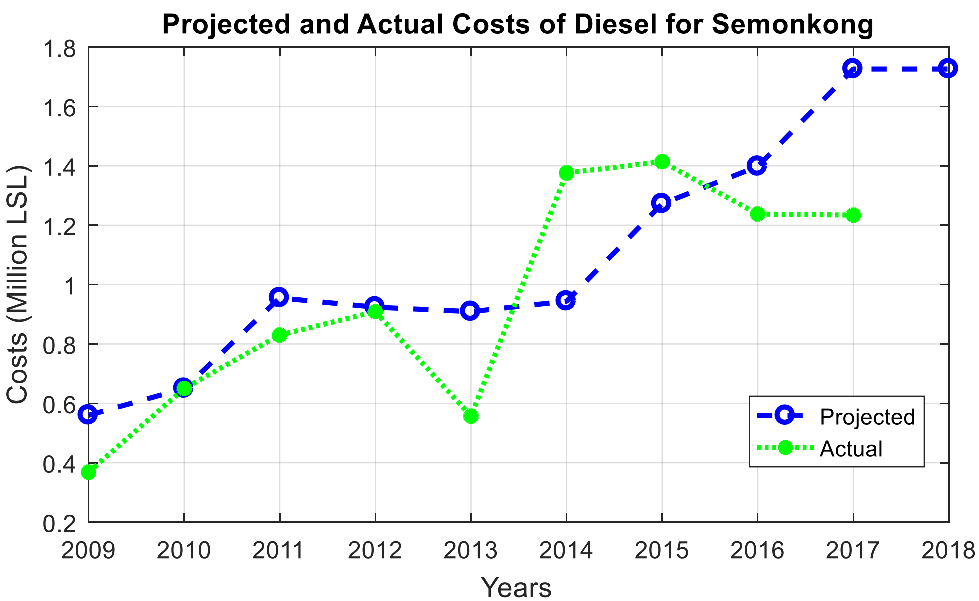
2012/13 Electricity Production

- Total energy production for the year – 504,801 kWh (89% hydro, 11% diesel)
- However, diesel is expensive and subject to price fluctuations
  - Utility used M0.5572m (US$39,800) for diesel & oil in 2012/13:
    - Translating to M9.8433/kWh or US$0.7031/kWh
  - 10 times more expensive compared with approved unit tariffs for:
    - General purpose – M1.0135/kWh or US$0.0724/kWh
    - Domestic – M0.9033/kWh or US$0.0645/kWh



Study Objectives

- As diesel prices increase, diesel-dependent mini-grids will prove to be more expensive on a lifetime basis than hybrid ones
  - This strengthens the case for decentralized generation using locally-available renewable resources of solar, wind and hydro where feasible

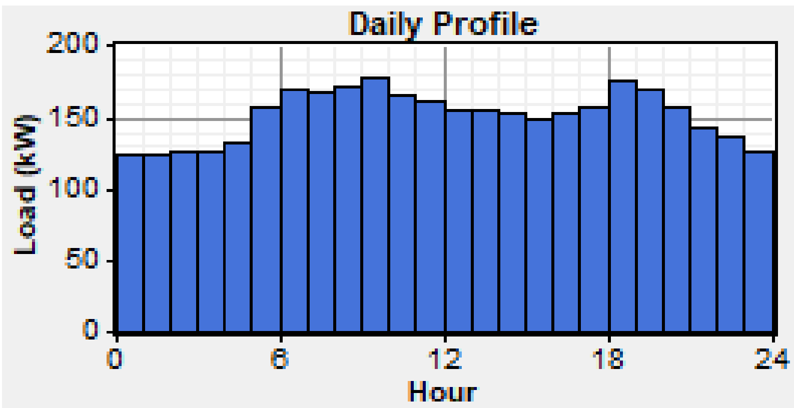


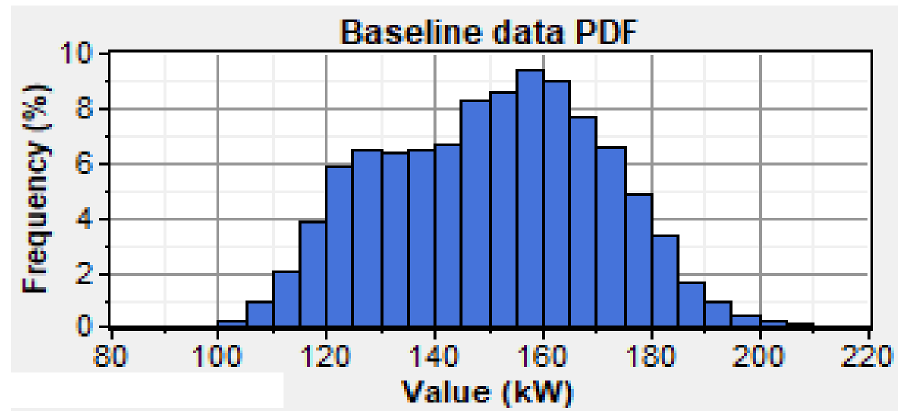
- This study therefore seeks, using HOMER software, to evaluate the type of renewable energy technologies (RETs) that are mostly favourable for the case study of Semonkong town, in Lesotho.

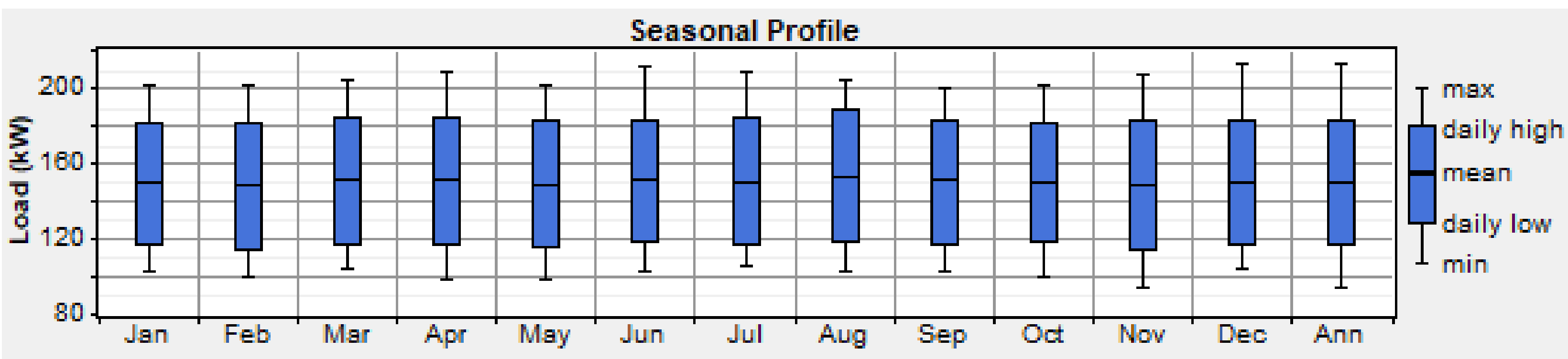
- It will answer 3 research questions:
  - Is it feasible and cost-effective to supply the town completely from renewable energy?
  - Is it critical to add battery bank and diesel generator back-up systems?
  - Will the proposed hybrid power system design meet the growing electricity demand?

2016/17 Load Profile

- HOMER load profile simulation with 5% random variability



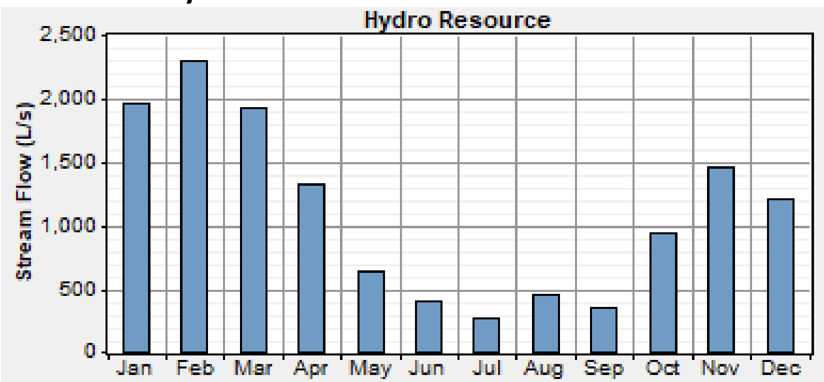




- Peak demand – 212 kW; Average load – 150 kW
- Average energy consumption – 3,611 kWh/day; Load factor – 70.9%

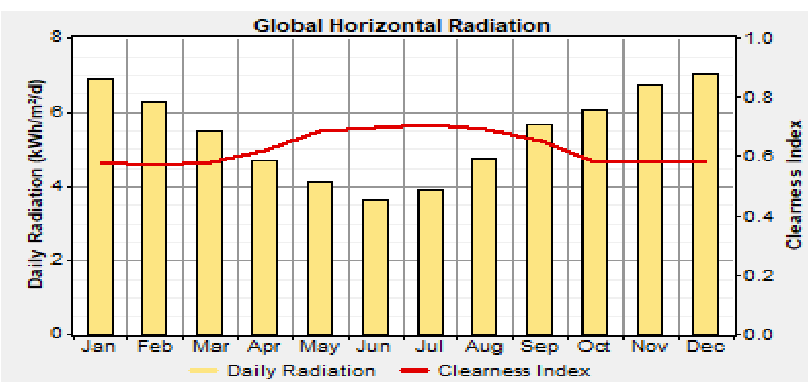
Renewable Resources Availability

- Hydro



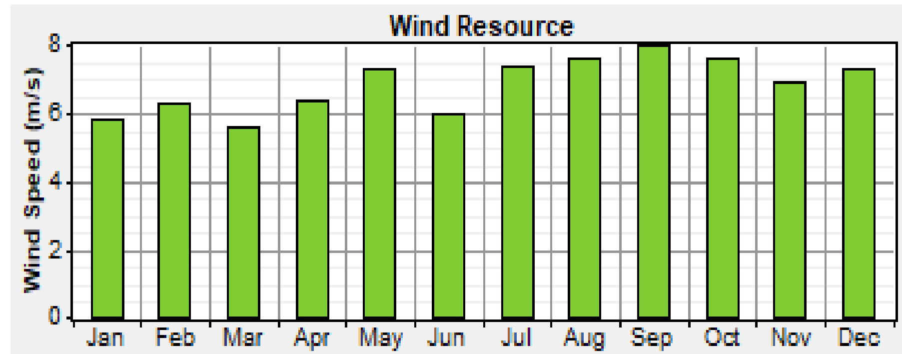
  - Annual average flow rate: 1,095 L/s

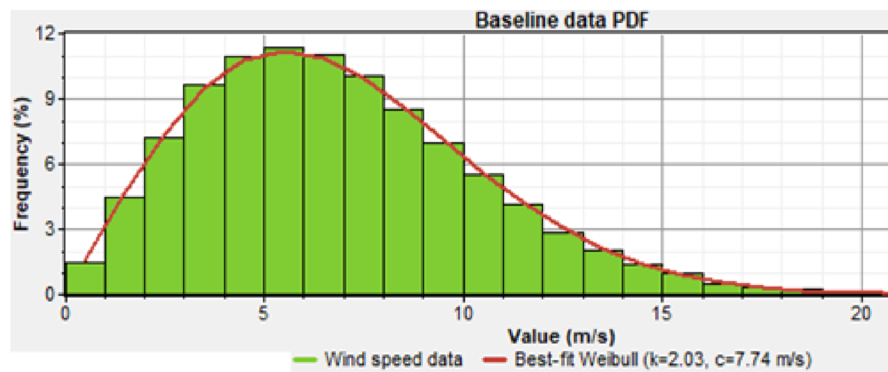
- Solar



  - Average radiation: 5.43 kWh/m2/d

- Wind





  - Average wind speed: 6.85 m/s

Simulation Results (1)

Calculate | Simulations: 256 of 256 | Sensitivities: 270 of 270 | Progress: | Status: Completed in 9:41.

Sensitivity Results | Optimization Results

Sensitivity variables

Primary Load 1 (kWh/d) 3,611 | Global Solar (kWh/m²/d) 5.43 | Wind Speed (m/s) 6.85

Stream Flow (L/s) 1,095 | Diesel Price ($/L) 0.75

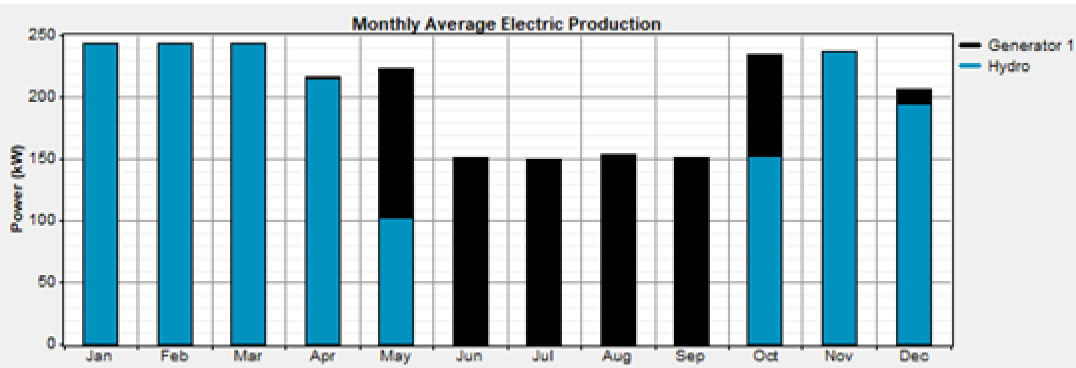
Double click on a system below for simulation results. | Categorized | Overall | Export... | Details...

PV (kW)	FL250	Hydro (kW)	Gen (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	1	180	400	1600	200	$ 1,184,200	212,130	$ 3,895,932	0.231	0.89
200	1	180	400	1600	200	$ 1,748,600	172,143	$ 3,949,161	0.234	0.95
400		180	400	2400	200	$ 2,440,000	285,999	$ 6,096,023	0.362	0.87
		180	400	1600	200	$ 1,131,200	398,183	$ 6,221,314	0.369	0.66
400	1	180	400		200	$ 1,953,000	415,697	$ 7,267,005	0.431	0.89
	1	180	400		200	$ 824,200	514,734	$ 7,404,231	0.439	0.82
400		180	400		200	$ 1,900,000	509,141	$ 8,408,532	0.499	0.81
		180	400		200	$ 771,200	619,368	$ 8,688,796	0.516	0.66

- Existing hydro/diesel hybrid is ranked lowest as the least cost-effective option at LCOE of US$0.516/kWh (M7.224/kWh) and 0.66 renewable energy fraction
- Wind/hydro/diesel/battery combination that excludes the solar PV component is the most cost-effective mini-grid solution for Semonkong with LCOE of US$0.231/kWh (M3.234/kWh) and a renewable energy fraction of 0.89

Simulation Results (2)

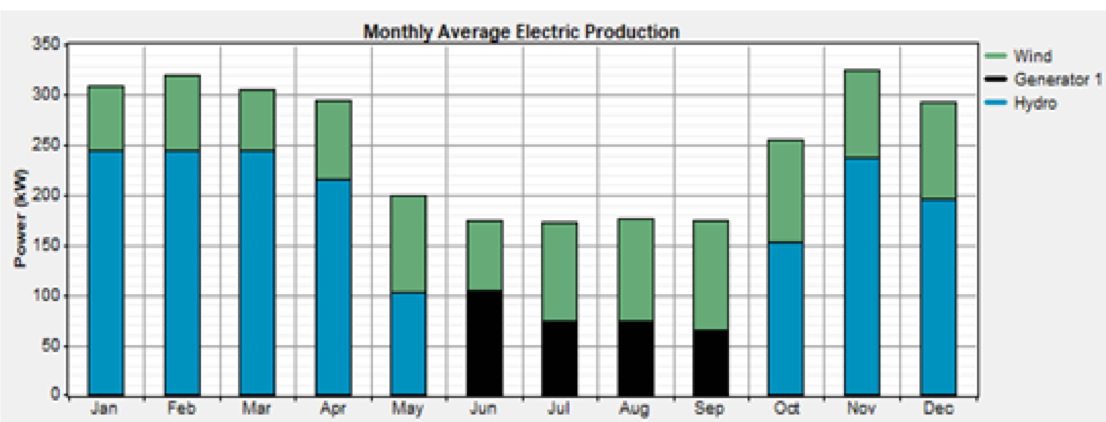
- Hydro/diesel



- LCOE – US$0.516/kWh (M7.224/kWh)
- Ren. Frac. – 0.66 (66% hydro, 34% diesel)
- Excess generation – 26.4%

- Effective during rainy summer but requires diesel genset support during dry winter months

- Wind/hydro/diesel/battery

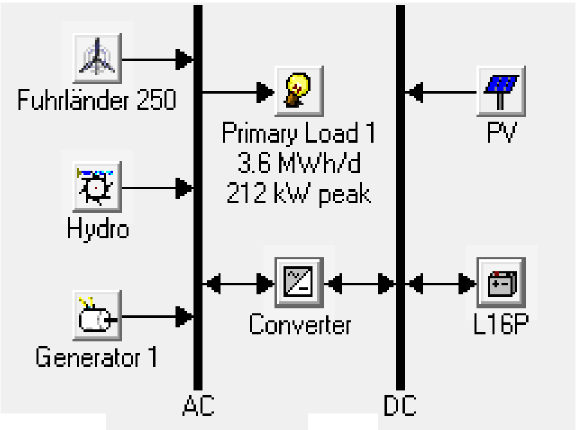


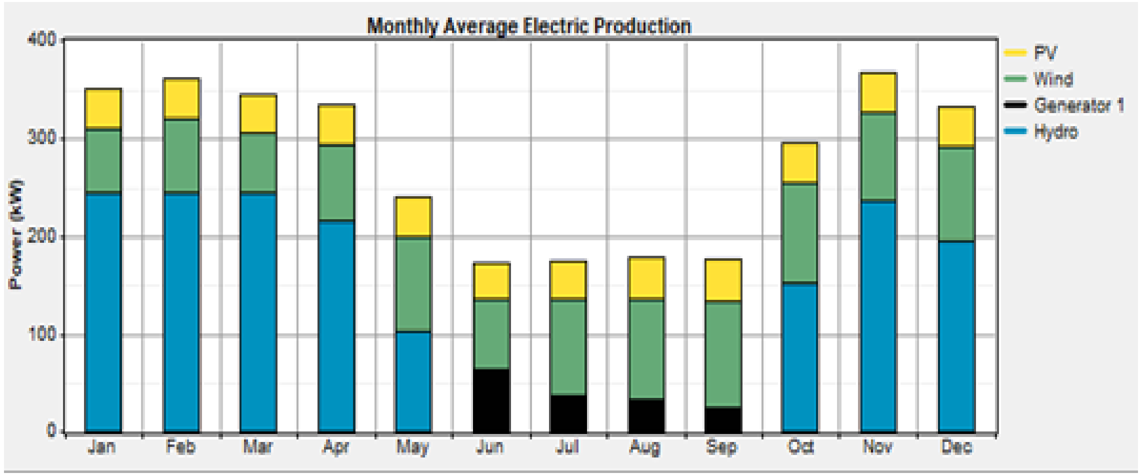
- LCOE – US$0.231/kWh (M3.234/kWh)
- Ren. Frac. – 0.89 (35% wind, 54% hydro, 11% diesel)
- Excess generation – 36.4%

- Diesel genset support in winter reduced by the wind component

Optimization Results

- PV/wind/hydro/diesel/battery





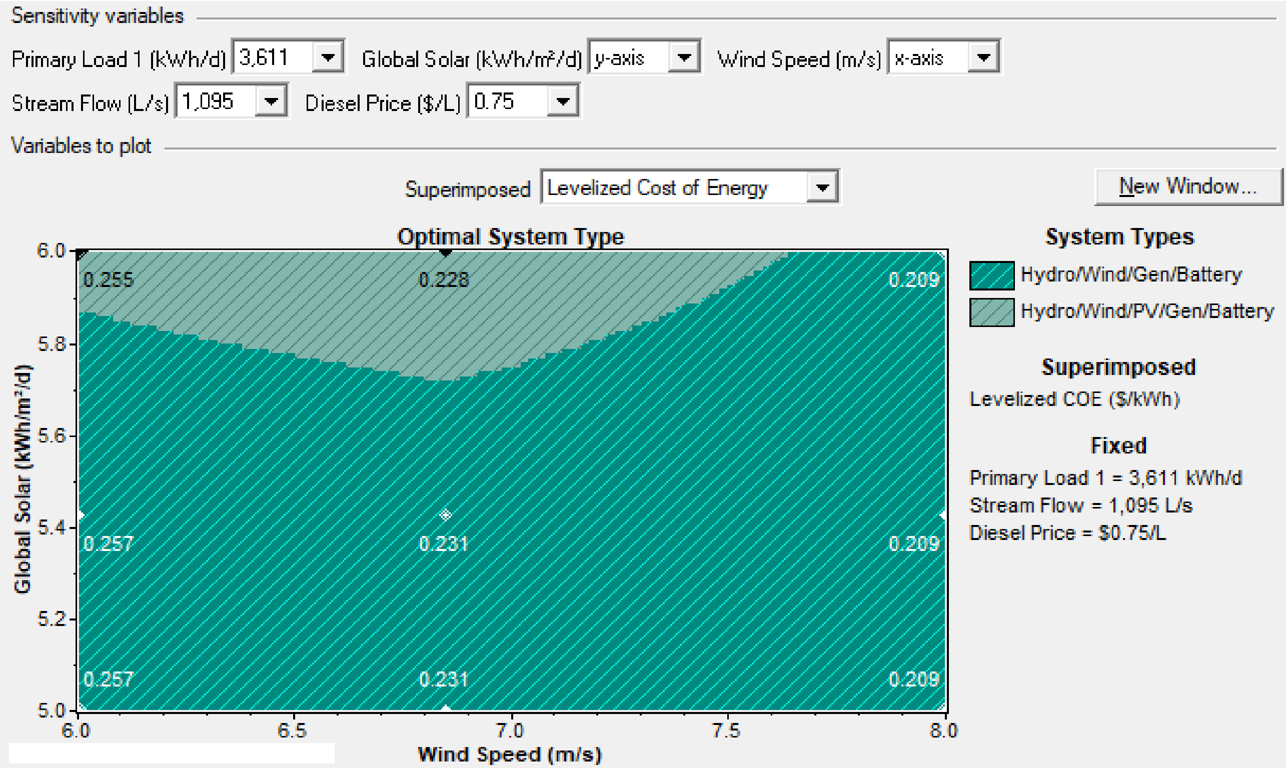
- Exploits or optimizes use of all the available renewable resources to make the system almost independent of diesel

- LCOE – US$0.234/kWh (M3.276/kWh)
- Ren. Frac. – 0.95 (15% PV, 32% wind, 49% hydro, 5% diesel)
- Excess generation – 43.3%

- One clear deduction from the results is that it will not be possible to supply Semonkong on RETs only as the diesel generator is always required in any system configuration to meet the local demand especially in winter

Sensitivity Analysis Results (1)

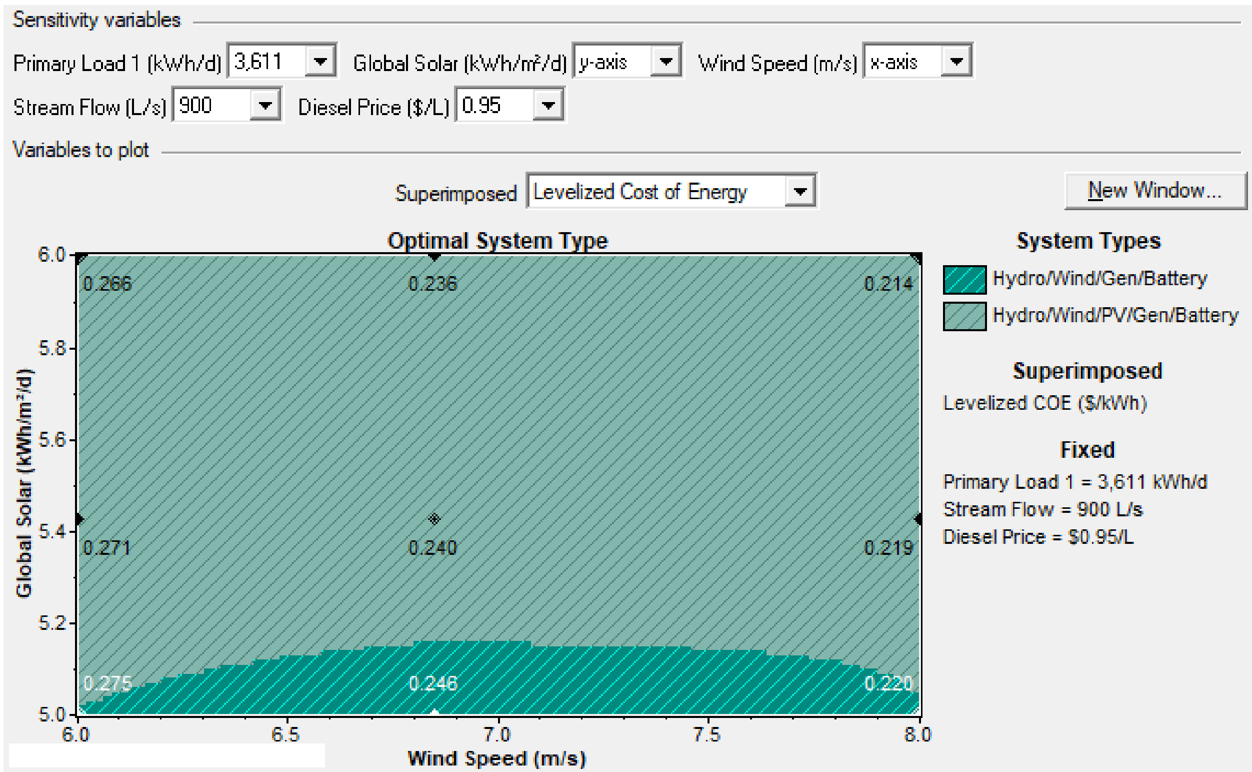
- Optimal system with fixed load, stream flow and diesel price



- When the solar radiation increases to about 5.8 kWh/m^2/d or higher, the hydro / wind / PV / diesel / battery hybrid slightly becomes the cost-effective solution, provided the wind speed is below 7.6 m/s
- Otherwise the hydro/wind/diesel/battery hybrid dominates with LCOE of US$0.209/kWh (M2.926/kWh) to US$0.257/kWh (M3.598/kWh)

Sensitivity Analysis Results (2)

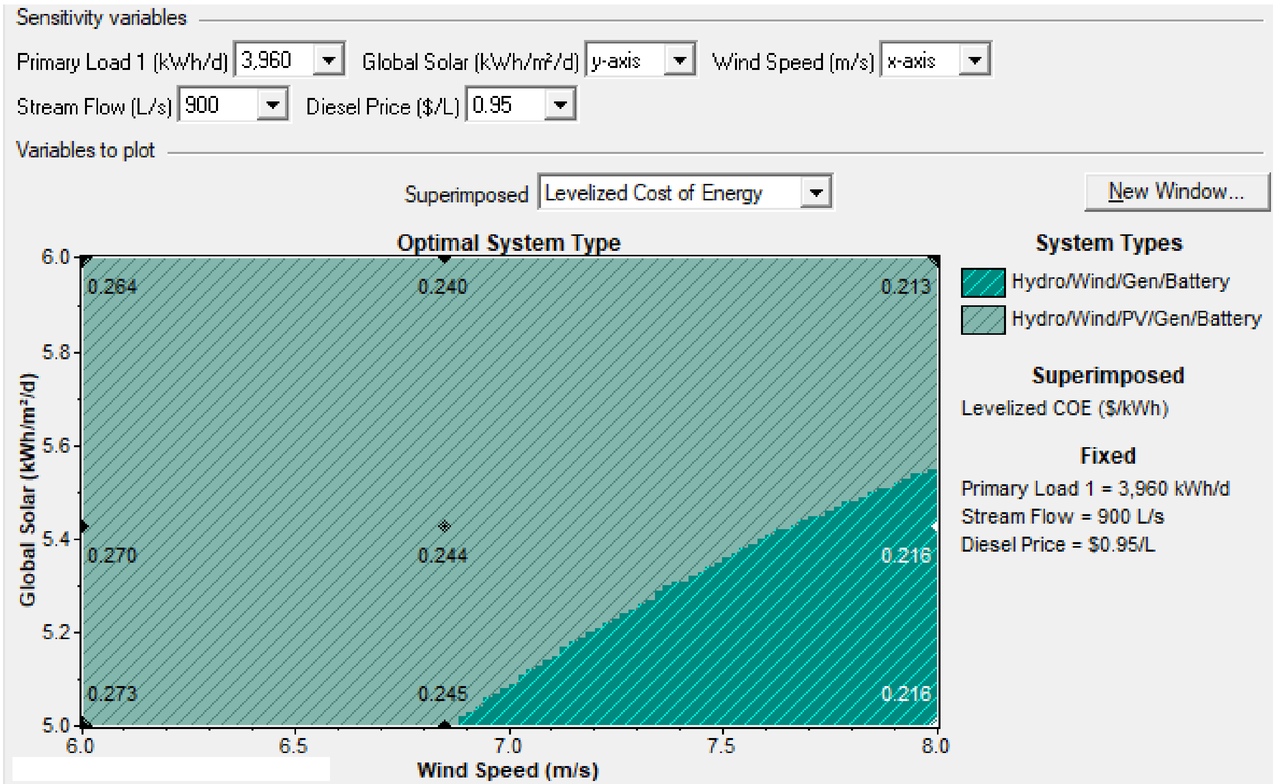
- Optimal system with fixed load, lower stream flow and higher diesel price



  - Hydro/wind/PV/diesel/battery system architecture becomes the most optimal combination for majority of the conditions, with LCOE of US$0.214/kWh (M2.996/kWh) to US$0.275/kWh (M3.85/kWh)
  - But when the solar radiation goes below 5.2 kWh/m^2/d, the hydro/wind/diesel/battery hybrid without the PV component becomes more cost-effective

Sensitivity Analysis Results (3)

- Optimal system with 30% load increase, lower stream flow and higher diesel price



  - Hydro/wind/PV/diesel/battery system architecture dominates, with LCOE varying from US$0.213/kWh (M2.982/kWh) to US$0.273/kWh (M3.822/kWh)
  - Increased average demand of 195 kW (from 150 kW) will be met mainly by the diesel generator, leading to a reduced renewable fraction of 0.93 from 0.95

Conclusions

- Technically, decentralized hybrid power generation using mainly local renewable energy resources can be a cost-effective means of supplying affordable and reliable power for rural communities like Semonkong in Lesotho.

- When compared with the existing Semonkong hydro/diesel hybrid at the LCOE of US$0.516/kWh and 0.66 renewable fraction, a full hydro/wind/PV/diesel/battery hybrid system configuration could lower the costs by more than half to US$0.234/kWh with a higher renewable energy fraction of 0.95.

- Clearly, the diesel generator backup will always be required to ensure reliability and quality of supply when the RETs are low.

- The sensitivity analysis results further indicated that due to varying local natural conditions of solar, hydro and wind at the site, LCOE can vary from a minimum of US$0.209/kWh to a maximum of US$0.275/kWh.

- Increase in local demand of around 30% would still be met by the chosen optimal hybrid system at a slightly reduced renewable fraction of 0.93.