11.8-100% Rural Renewable Energy and Power Supply and its Influence on the Luxembourgish Power System

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Motivation
How to design a rural renewable power supply and how much does it cost to meet the different "energy scenarios"? This question is answered in the following, supplying an average Luxembourgish village with power generated from renewables. A low price as well as a low energy import from the grid is the goal of the proposed energy system.

Concept
A Luxembourgish average sample village is designed, consisting of the main consumer, namely, private households, farms and service consumer. The village has 255 inhabitants and 94 households, which represents the median of the rural population. The power demand is 481 MWh/a.

Using the standard load profiles (H0, G1, G2, G4, G5) for the different consumer a village profile was derived. The following renewable energy scenarios are analysed:
1. 11.8%: Luxembourgish Goal for 2020
2. 30%: European goal for 2030
3. 100%: Theoretical energy goal for a renewable supply

Optimized Renewable Generation
Using a number of three decentralized renewable concepts which can be directly feed into the 400V grid a 8.5 kW solar PV, a 100 kW wind power plant and a 20 kW hydrokinetic turbine are considered in the optimization. The systems annuities are: Solar (8.5 kW): 972.30 EUR/a; wind (100kVA): 20976.79 EUR/a; hydrokinetic (20kVA): 2129 EUR/a, each calculated for 13 years.

The cost optimization aims on a minimum cost to supply the villages’ electricity demand. A minimal cost solution for the considered time span of 3 years is derived using real generation profiles of the three renewable technologies.

The IBM Cplex solver was used to find the optimal solution of the problem defined in Matlab.

The number of PV systems is restricted to the maximum number of households, 94. The number of hydrokinetic turbines is restricted by the line losses and therefore by the distance of the turbine to the village. The number of wind power plants is restricted by the length of a circle around the village and its diameter and the turbines minimum distance to each other.

Limited number of wind turbines: 

\[ N_{\text{wind}} = \left( \frac{N_{\text{inhabitants}}}{1500} + 0.282 \right)^{\frac{m}{6}} \]

Results
The results of the optimization show that for different energy scenarios the prices and the systems’ performance vary.

It is interesting to see that up to 100% renewable energy supply in Luxembourgish villages the solar PV generation is the most cost effective solution with 14 ct/kWh.

Locations with a higher wind speed make hybrid solutions of wind and solar systems more efficient. So the price for the best wind speed location is just 8.4ct/kWh.

The innovative hydrokinetic turbine in a 100% renewable hybrid energy scenario leads to higher generation prices of about 19.6 ct/kWh.