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11,8-100% Rural Renewable Energy and Power Supply and its Influence on the Luxembourgish Power System

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Motivation

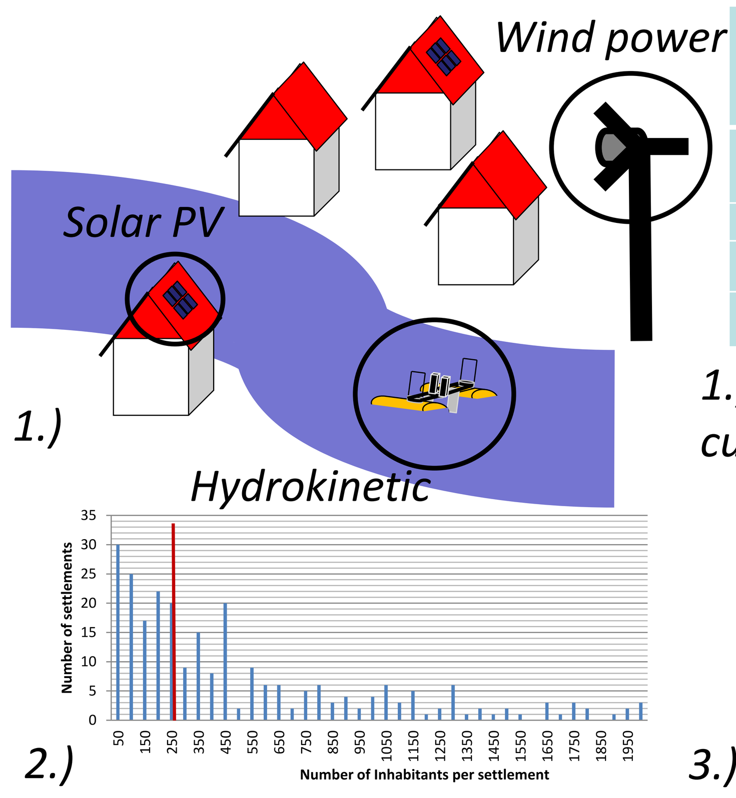
How to design a rural renewable power supply and how much does it cost to meet the different "energy scenarios"? This question is answered in the following, supplying an average Luxembourgish village with power generated from renewables. A low price as well as a low energy import from the grid is the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

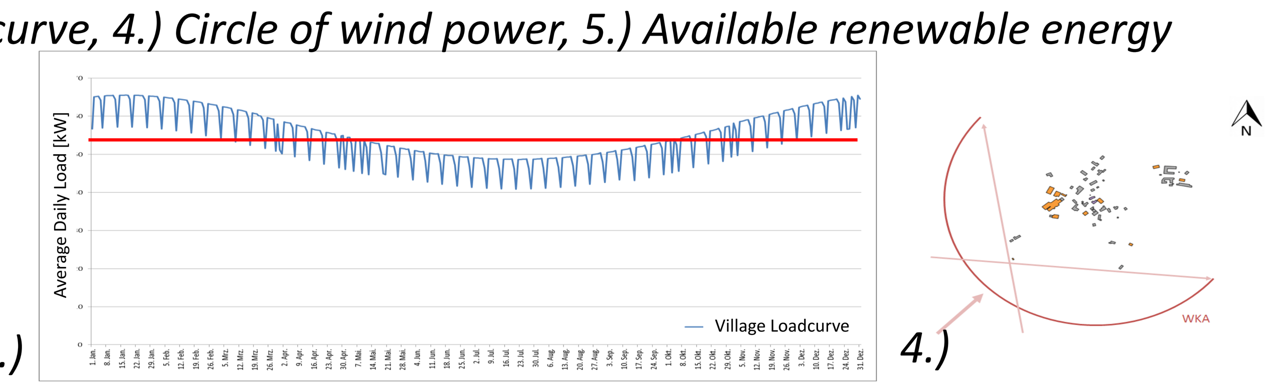
1. 11.8 %: Luxembourgish Goal for 2020
2. 30 %: European goal for 2030
3. 100 %: Theoretical energy goal for a renewable supply



5.)

	Solar	Wind power (average speed in 35m)			Hydrokinetic
		3.92 m/s	5.22 m/s	6.59 m/s	
Rated power	8,5 kWp	100 kVA			20 kVA
Annual full-load hours [h]	817.9	1165.0	2185.7	3453.1	340.3
Energy generation [kWh/a]	6952.3	116501.4	218574.9	345309.9	6806.6
Generation cost [EUR/kWh]	0.140	0.181	0.096	0.061	0.313

1.) Schematic settlement, 2.) Inhabitant distribution, 3.) Load curve, 4.) Circle of wind power, 5.) Available renewable energy



Optimized Renewable Generation

Using a number of three decentralized renewable concepts which can be directly feed into the 400V grid a 8.5kW solar PV, a 100 kVA wind power plant and a 20 kVA 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 9 years is derived using real generation profiles of the three renewable technologies.

The IBM Ceplex solver was used to find the optimum 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.

Component	Lifespan	Cost
Turbine and tower	30 years	255 000 EUR
Foundation	60 years	50 000 EUR
Grid connection	30 years	15 000 EUR
Spare parts	30 years	8000 EUR
Insurance and taxes	-	1150 EUR
Maintenance	-	3500EUR

Component	Lifespan	Cost
Solar Panel 250 W	25 years	192.00 EUR/panel
Inverter	13 years	2058.00 EUR/piece
Grid connection	30 years	198.00 EUR fix
Spare parts	-	34.00 EUR/panel
Insurance and taxes	-	37.50 EUR/panel
Maintenance	-	42.50 EUR/panel
Maintenance and Insurance	-	240 EUR fix

Component	Lifespan	Cost
Entire System	30 years	22730 EUR
Generators	17 years	3842 EUR
Inverter	13 years	4882 EUR
Roller bearings	15 years	800 EUR
Maintenance	-	450EUR/a
Insurance	-	113.65 EUR/a

Optimization: $\min_{x \in \mathbb{N}_0} \{c^T x \mid Ax \geq b\}$

$$Ax \geq b = \begin{bmatrix} P_{solar,1} & P_{wind,1} & P_{hydr,1} \\ \cdots & \cdots & \cdots \\ P_{sol,m} & P_{wind,m} & P_{hydr,m} \end{bmatrix} * \begin{bmatrix} x_{solar} \\ x_{wind} \\ x_{hydr} \end{bmatrix} \geq \begin{bmatrix} P_{Demand,1} \\ \cdots \\ P_{Demand,m} \end{bmatrix}$$

$$c^T x = \begin{bmatrix} x_{sol} \\ x_{wind} \\ x_{hydr} \end{bmatrix}^T x \qquad a_t x = \sum_{i=1}^{n} [a_{i,t} * x_i] = \sum_{i=1}^{3} [P_{i,t} * x_i]$$

$$c^T x = \sum_i (c_i * x_i) = c_{solar} * x_{solar} + c_{wind} * x_{wind} + c_{hydr} * x_{hydr} \rightarrow min$$

Energy Constraint: $p * E_{Load} \leq E_{Solar} * x_{Solar} + E_{Wind} * x_{Wind} + E_{Hydro} * x_{Hydro}$

Limited number of wind turbines: $N_{Turbines}(N_{Inhabitants}) = \frac{1000 \frac{m}{km} * \pi}{6 * 25{,}4} * \left(\sqrt{\frac{N_{Inhabitants}}{150\pi}} + 0{,}282 \right)$

Length of sound transmission: $r = r_0 * 10^{\left(\frac{L_S - L_r - 11dB}{20dB}\right)}$

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 8.4€ct/kWh.

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

Scenario (Wind speed)	11.8% (mean)	30% (mean)	100% (min.)	100% (mean)	100% (max.)	100% with Hydro
PV-Systems [-]	9	21	70	4	20	47
Wind turbines [-]	0	0	0	2	1	0
Hydrokinetic [-]	0	0	0	0	0	23
Annual energy production [MWh]	62.57	146.00	486.66	484.63	484.35	483.31
Energy balance [MWh]	-419.65	-336.22	4.44	2.41	2.13	1.09
Direct energy consumption [MWh]	62.52	130.12	207.43	259.91	313.45	235.44
Annual deficit for only directly consumed electricity [MWh]	419.7	352.10	274.79	222.31	168.77	246.77
Excess energy for direct consumption [MWh]	0.05	15.88	279.23	224.72	170.89	247.86
Max. Residual load (Import) [kW]	105.9	105.9	105.9	105.8	105.8	105.6
Max. Excess power (Export) [kW]	27.6	144.3	650.1	183.1	234.0	632.2
Power directly supplied (share of a year) [%]	0.1	8.6	28.1	34.8	44.1	30.3
Annual Energy supply [%]	13.0	30.3	100.9	100.5	100.4	100.2
Generation cost [EUR/kWh]	0.140	0.140	0.140	0.095	0.084	0.196

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