Postgraduate program: Environment and Development

Course: Energy and Environment

National Technical University of Athens

Exercise instructions: Use of renewables sources in the energy mix

The energy mix for the production of electrical energy on an island with a population of 1000 is being designed. It has been decided to prioritise the use of renewable sources of energy and only use fossil fuels in case of emergencies. In particular, the following options are considered:

- the installation of wind turbines with power of 500 and 850 kW
- the installation of a photovoltaic station with power of 100 kW
- the installation of a biomass combustion unit, with a thermal power of 4 kWh/kg and efficiency of 40%
- the construction of a pumped storage scheme, with an elevation difference of 100 m, combined efficiency of 88% and hydraulic losses of 5%.

The following are requested:

1. the required annual electrical energy, the minimum total power that needs to be installed and the capacity factor of the entire system
2. the characteristics of the energy balance on an hourly basis (the produced and the discarded energy, the failure rate in meeting demand) for various combinations of installed wind turbines and photovoltaic stations
3. the required quantity for biomass and fossil fuels, so that the energy deficits are completely covered
4. the required mean annual water inflow in the pumped storage scheme, that results in the maximum possible coverage of energy deficits and surpluses

The following are provided in the Excel file:

- Hourly 10-year timeseries of wind speed, solar radiation and estimated electric energy demand
- Characteristic quantities of wind turbines and photovoltaic stations

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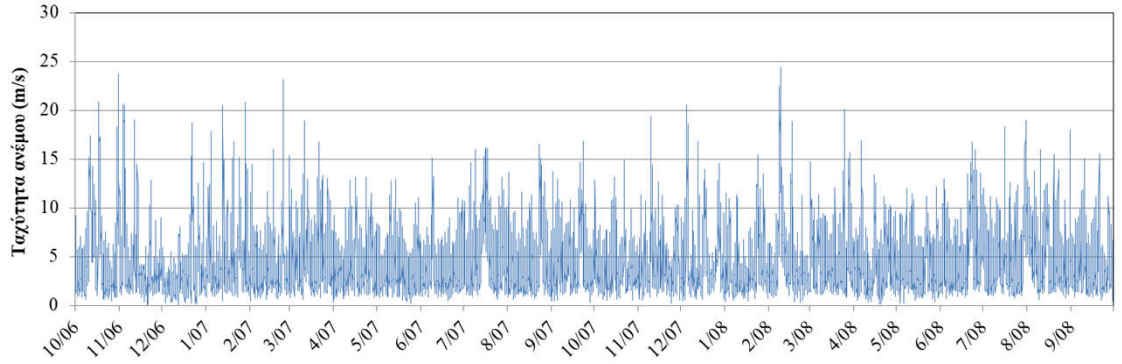
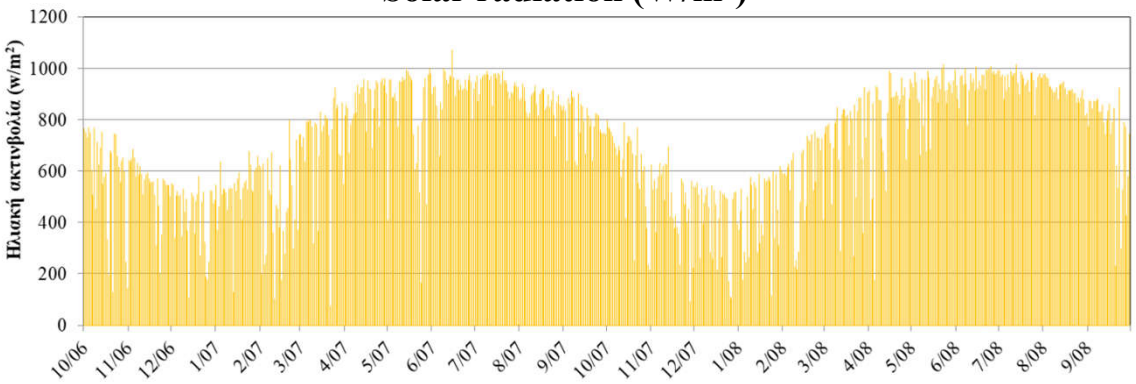
Available Data

Hourly time series

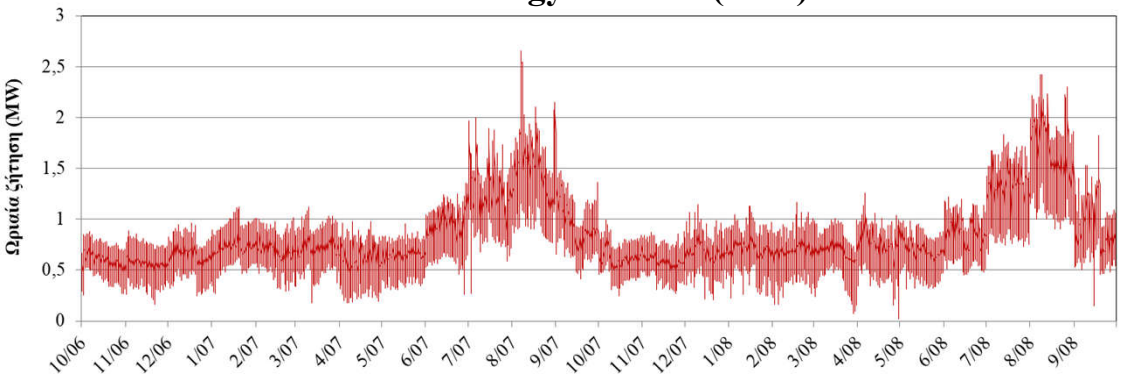
Wind velocity (m/s)



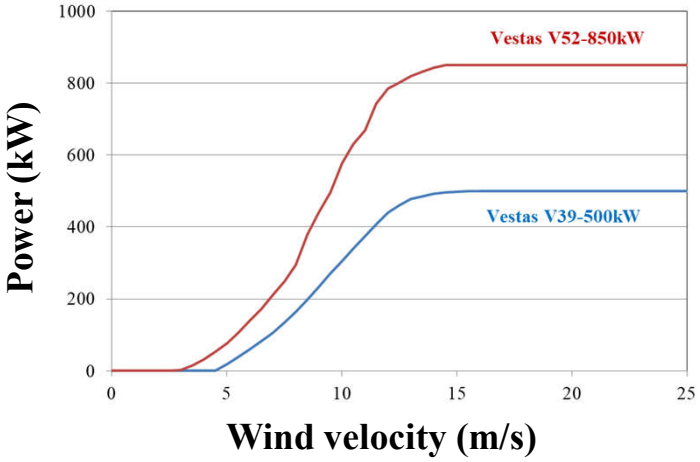
Solar radiation (W/m^2)

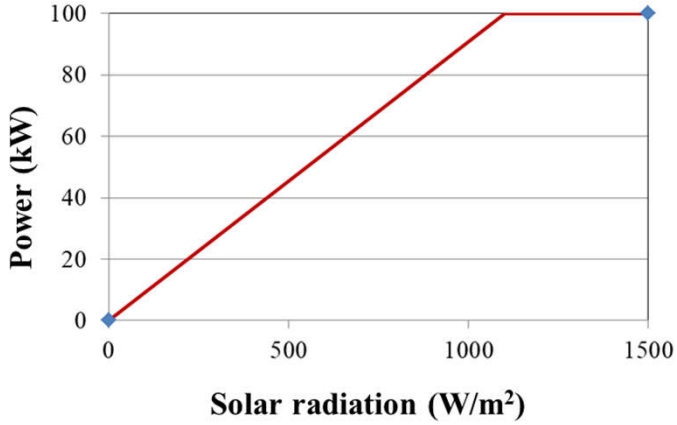


Electric energy demand (MW)



Wind turbines and PV panel curves

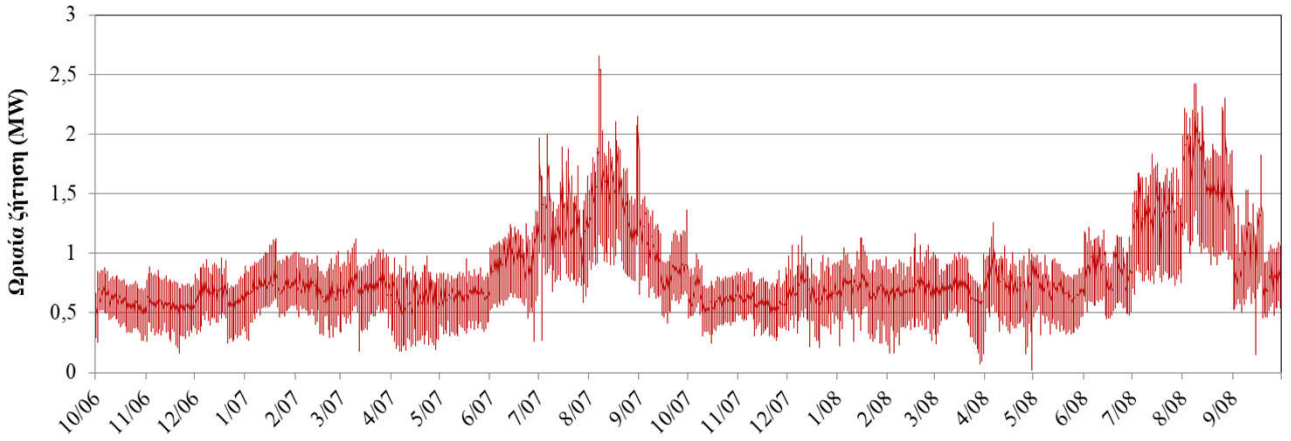




1. Electric energy demand

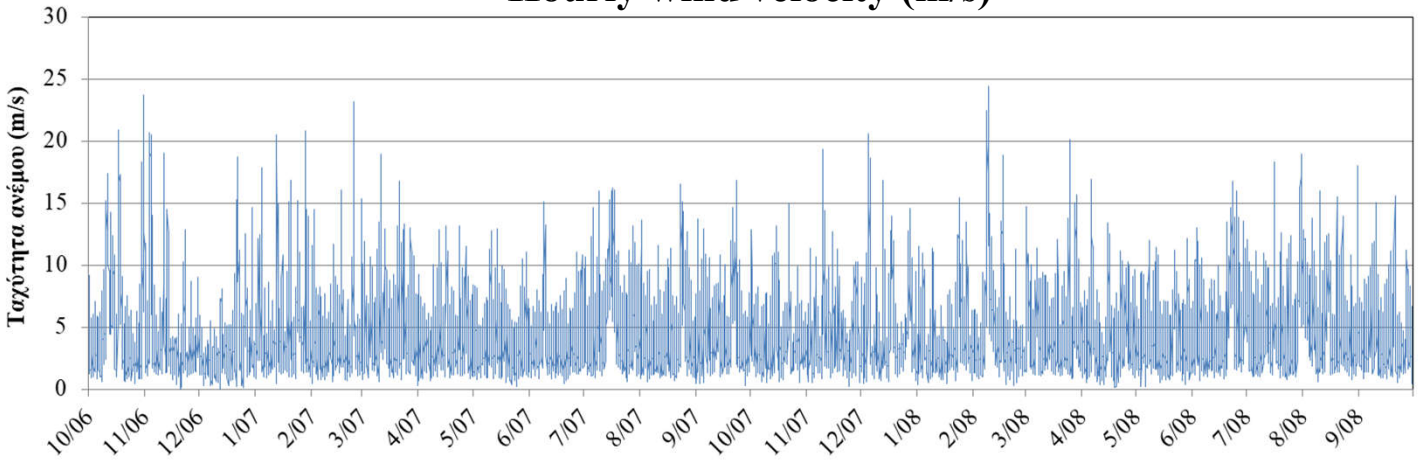
1		
2		Power kW
3		number
4		
5	Energy MWh/y	6311,1
6	max hourly	2,72
7	mean hourly	0,72
8	minhourly	0,02
9	Capacity factor	*0,26*
10		
11		
12		
13		Demand MWh
14	Date	
15	1/10/2006 0:00	0,66
16	1/10/2006 1:00	0,47
17	1/10/2006 2:00	0,47
18	1/10/2006 3:00	0,48
19	1/10/2006 4:00	0,44
20	1/10/2006 5:00	0,38

Hourly electric energy demand (MW)



2.1 Estimation of wind energy production

Hourly wind velocity (m/s)



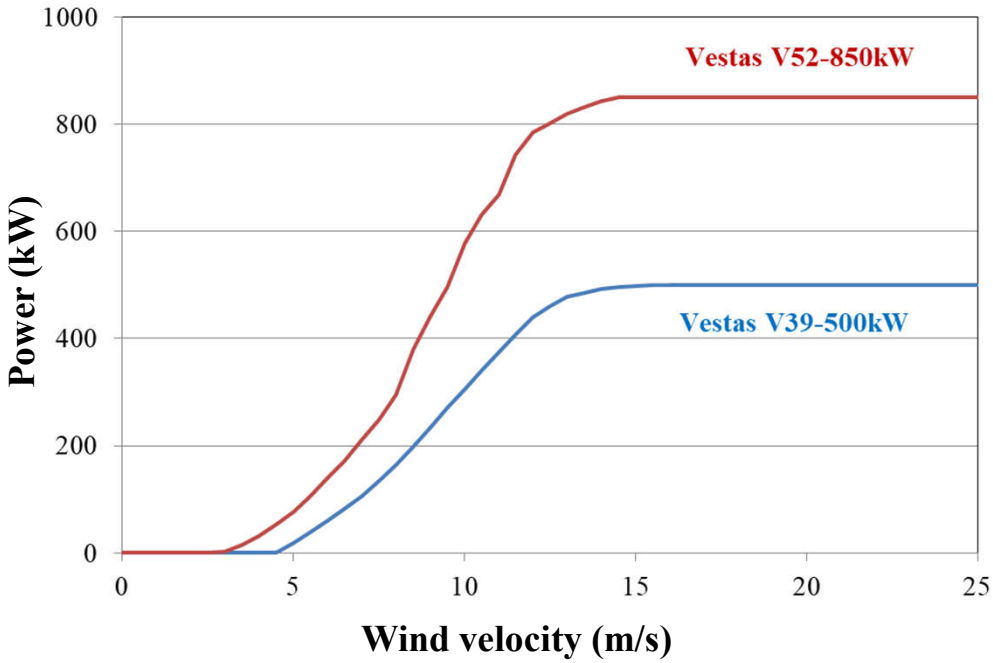
Estimation of wind velocity at the altitude of wind turbine

Roughness length, z_0, is a corrective measure to account for friction effects to wind flow due to terrain obstacles (**very sensitive parameter**).

In order to estimate the mean wind speed u_2 at a height z_2 based on a known (measured) value u_1 at a height z_1, the formula is rearranged as:

$$\frac{u_2}{u_1} = \ln\left(\frac{z_2}{z_0}\right) / \ln\left(\frac{z_1}{z_0}\right)$$

Wind turbine curves



2.1 Estimation of wind energy production

Estimation of energy production considering the wind velocity and wind turbine curve

WindCalc sheet

=(IF(H11<=25;LOOKUP(H11;$A$11:$A$261;$B$11:$B$261);0))/1000

	A	B	C	D	E	F	G	H	I	J	K	L
1	ΔΕΔΟΜΕΝΑ											
2	z0 =	0,02										
3	z1 =	3										
4	z2 =	53	86						CF		0,30	0,33
5								Ετήσια Ενέργεια (MWh)			1312	2450
6											13121	24501
7							4,6	7,3	7,8		0,5	0,85
8											MWh	MWh
9							3	53	86		500kW	850 kW
10		500 kW		850 KW			m/s					
11	0	0	0	0		1/10/2006 0:00	1,7	2,7	2,9		0,0	0,0
12	0,1	0	0,1	0		1/10/2006 1:00	2,0	3,1	3,3		0,0	0,0
13	0,2	0	0,2	0		1/10/2006 2:00	2,3	3,6	3,9		0,0	0,0
14	0,3	0	0,3	0		1/10/2006 3:00	2,3	3,7	3,9		0,0	0,0
15	0,4	0	0,4	0		1/10/2006 4:00	1,7	2,7	2,9		0,0	0,0
16	0,5	0	0,5	0		1/10/2006 5:00	1,6	2,5	2,6		0,0	0,0
17	0,6	0	0,6	0		1/10/2006 6:00	3,2	5,1	5,4		0,0	0,1

Wind turbine curves

=G11*LN($B$4/$B$2)/LN($B$3/$B$2)

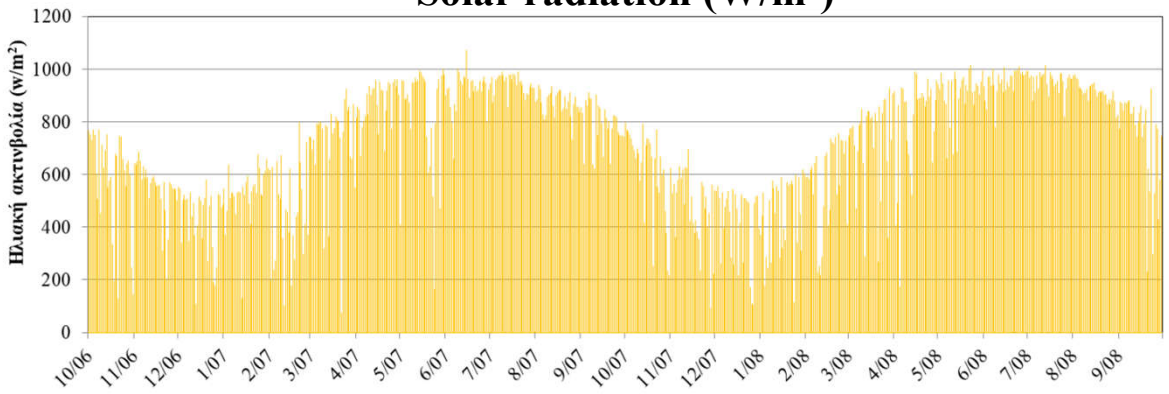
Estimation of wind velocity at the altitude of the wind turbine

2.2 Estimation of solar energy production

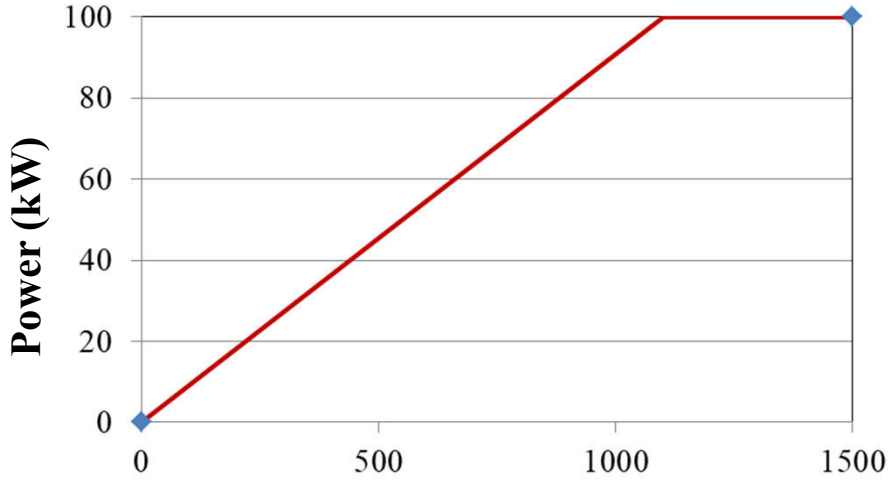
SunCalc sheet

	A	B	C	D
1		100 kW		
2		area	750	m2
3		efficiency	0,13	
4				
5		CF	0,196	
6	Energy (MWh/y)	1128,0000	172,0070	
7		IW/m2	P MWh	
8	1/10/2006 0:00	0	0,00	
9	1/10/2006 1:00	0	0,00	
10	1/10/2006 2:00	0	0,00	
11	1/10/2006 3:00	0	0,00	
12	1/10/2006 4:00	0	0,00	
13	1/10/2006 5:00	0	0,00	
14	1/10/2006 6:00	0,0	0,00	
15	1/10/2006 7:00	32,6	0,00	
16	1/10/2006 8:00	157,6	0,02	
17	1/10/2006 9:00	357,0	0,03	
18	1/10/2006 10:00	533,3	0,05	
19	1/10/2006 11:00	671,0	0,07	
20	1/10/2006 12:00	766,8	0,07	
21	1/10/2006 13:00	611,9	0,06	
22	1/10/2006 14:00	367,9	0,04	
23	1/10/2006 15:00	611,6	0,06	
24	1/10/2006 16:00	451,0	0,04	
25	1/10/2006 17:00	267,5	0,03	
26	1/10/2006 18:00	78,2	0,01	
27	1/10/2006 19:00	1,7	0,00	
28	1/10/2006 20:00	0,0	0,00	

Solar radiation (W/m²)



PV panels curve



Estimation of energy production considering solar radiation and the PV panels curve

=IF(B8*$C$2*$C$3/1000000<0,1;B8*$C$2*$C$3/1000000;0,1)

2.3 Energy balance in hourly basis

	A	B	C	D	E	F	G	H
1			turbine 1	turbine 2	Solar panels	Total installed		
2		Power kW	500	850	100	3600		
3		number	0	4	2			
4							Deficit	Surplus
5	Energy MWh/y	6311,1	0,0	9800,6	344,0	10144,6	-2667,1	6500,6
6	max hourly	2,72	0,00	3,40	0,20	3,60	-2,44	3,53
7	mean hourly	0,72	0,00	1,12	0,04	1,16	-0,30	0,74
8	minhourly	0,02	0,00	0,00	0,00	0,00		
9	Capacity factor	0,26	#DIV/0!	0,33	0,20	0,32		
10						Number ofdays	87672	
11						Number of Fails	47580	
12						Fails (%)	54,3	
13		Demand MWh	Production MWh					
14	Date		Turbines 1	Turbines 2	Solar panels	Total	Deficit	Surplus
15	1/10/2006 0:00	0,66	0,00	0,00	0,00	0,00	-0,66	0
16	1/10/2006 1:00	0,47	0,00	0,02	0,00	0,02	-0,45	0
17	1/10/2006 2:00	0,47	0,00	0,07	0,00	0,07	-0,39	0
18	1/10/2006 3:00	0,48	0,00	0,07	0,00	0,07	-0,40	0
19	1/10/2006 4:00	0,44	0,00	0,00	0,00	0,00	-0,44	0
20	1/10/2006 5:00	0,38	0,00	0,00	0,00	0,00	-0,38	0

=windCalc!K11*$C$3

=windCalc!L11*$D$3

=SunCalc!C8*$E$3

=C15+D15+E15

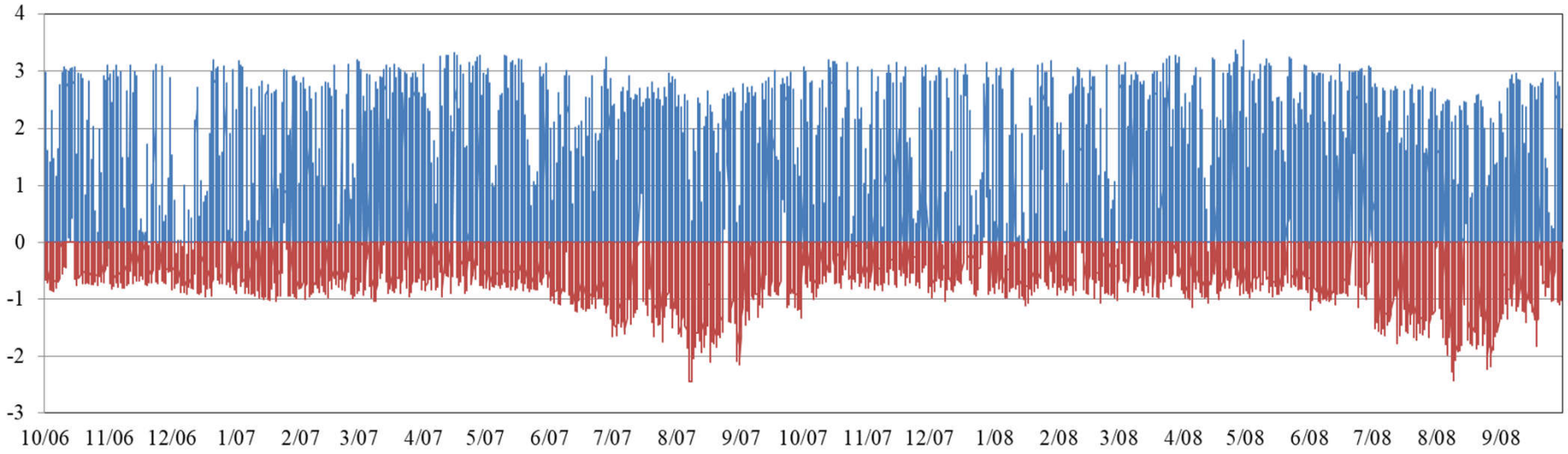
=IF(C15+D15+E15-B15<=0;C15+D15+E15-B15;0)

=IF(C15+D15+E15-B15>=0;C15+D15+E15-B15;0)

2.3 Energy balance in hourly basis

	Demand
Energy MWh/y	6311,1
Max hourly (kW)	2,72
Mean hourly (kW)	0,72
Min hourly (kW)	0,02
Capacity factor	0,26

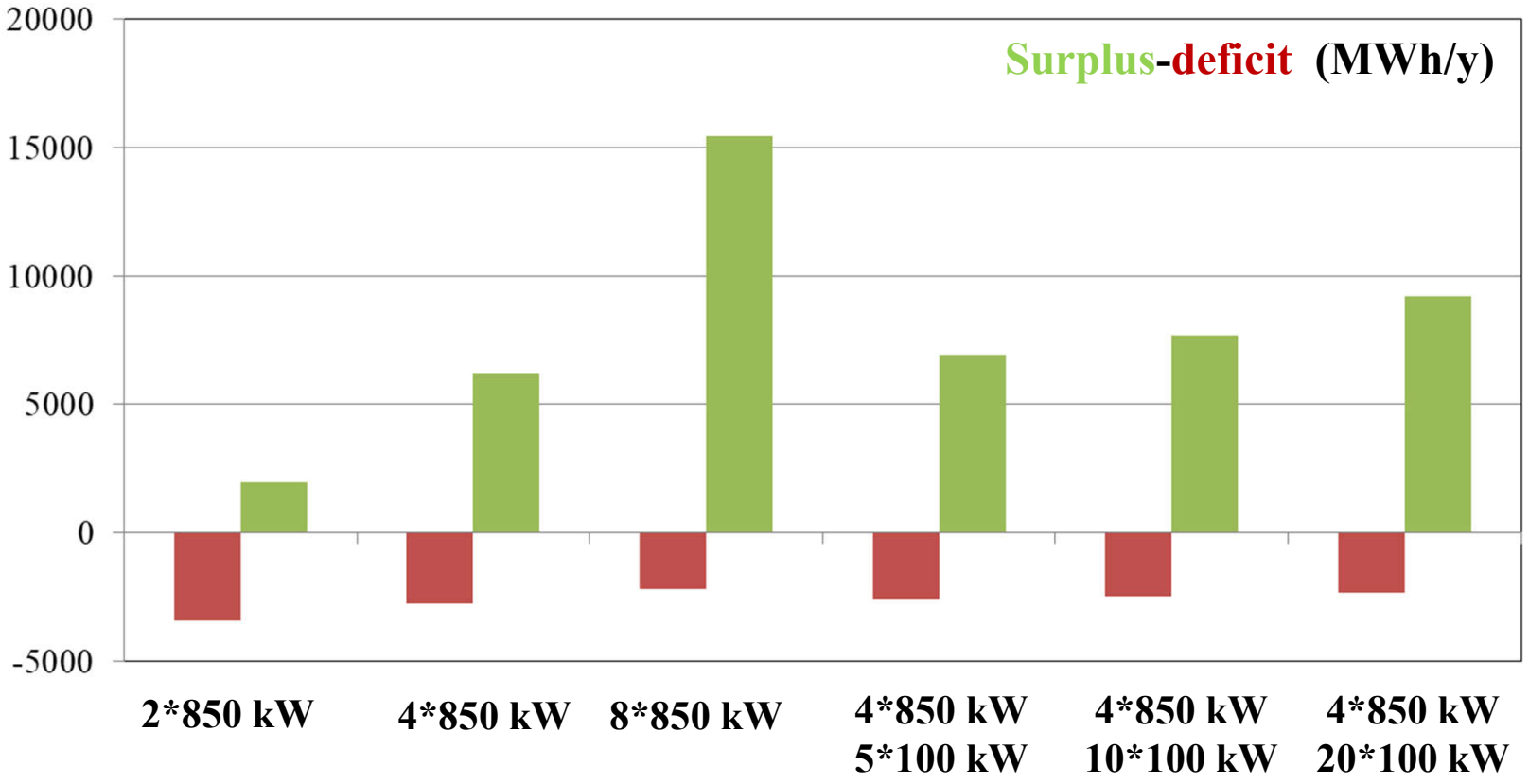
Hourly surplus-deficit using: **4*850 kW** wind turbines and **2*100 kW** panels



	Deficit	**Surplus**
Energy MWh/y	-2667,1	6500,6
Max hourly (kW)	-2,44	3,53
Mean hourly (kW)	-0,30	0,74
Hourly fails (%)	**54,3**	

2.3 Energy balance on an hourly basis

Annual surplus-deficit using various combinations



Hourly failure rate (%)	**67**	**55**	**44**	**52**	**50**	**47**

3. Covering energy deficits using other sources

Oil-Biomass

	G	H	I	J	K	L
1					**Oil**	**Biomass**
2				Calorific (kWh/kg)	12	4
3				efiiciency (%)	40	40
4	**Deficit**	**Surplus**	**Check**	MWh/tn	4,8	1,6
5	-2667,1	6500,6	**0,0**			
6	-2,44	3,53				
7	-0,30	0,74		tn/y	556	1667
8				I (MW)	2,44	2,44
9				CF	0,12	0,12
10	87672					
11	47580					
12	54,3			To cover deficit		
13				**Oil (tn)**	**Biomass (tn)**	
14	**Deficit**	**Surplus**				
15	-0,66	0		0,137	0,411	
16	-0,45	0		0,094	0,283	
17	-0,39	0		0,082	0,247	
18	-0,40	0		0,084	0,252	
19	-0,44	0		0,092	0,275	
20	-0,38	0		0,078	0,235	
21	-0,12	0		0,025	0,076	
22	-0,38	0		0,079	0,237	
23	-0,37	0		0,078	0,234	
24	-0,28	0		0,057	0,172	

=SUM(J15:J87686)/10

=-G6

=G5/(G6*8760)

=IF(G15<0;-G15/$L$4;0)

=IF(G15<0;-G15/$K$4;0)

4. Energy storage using hydropower

=P3*(P2-P2*P5/100)*1*9,81/3600

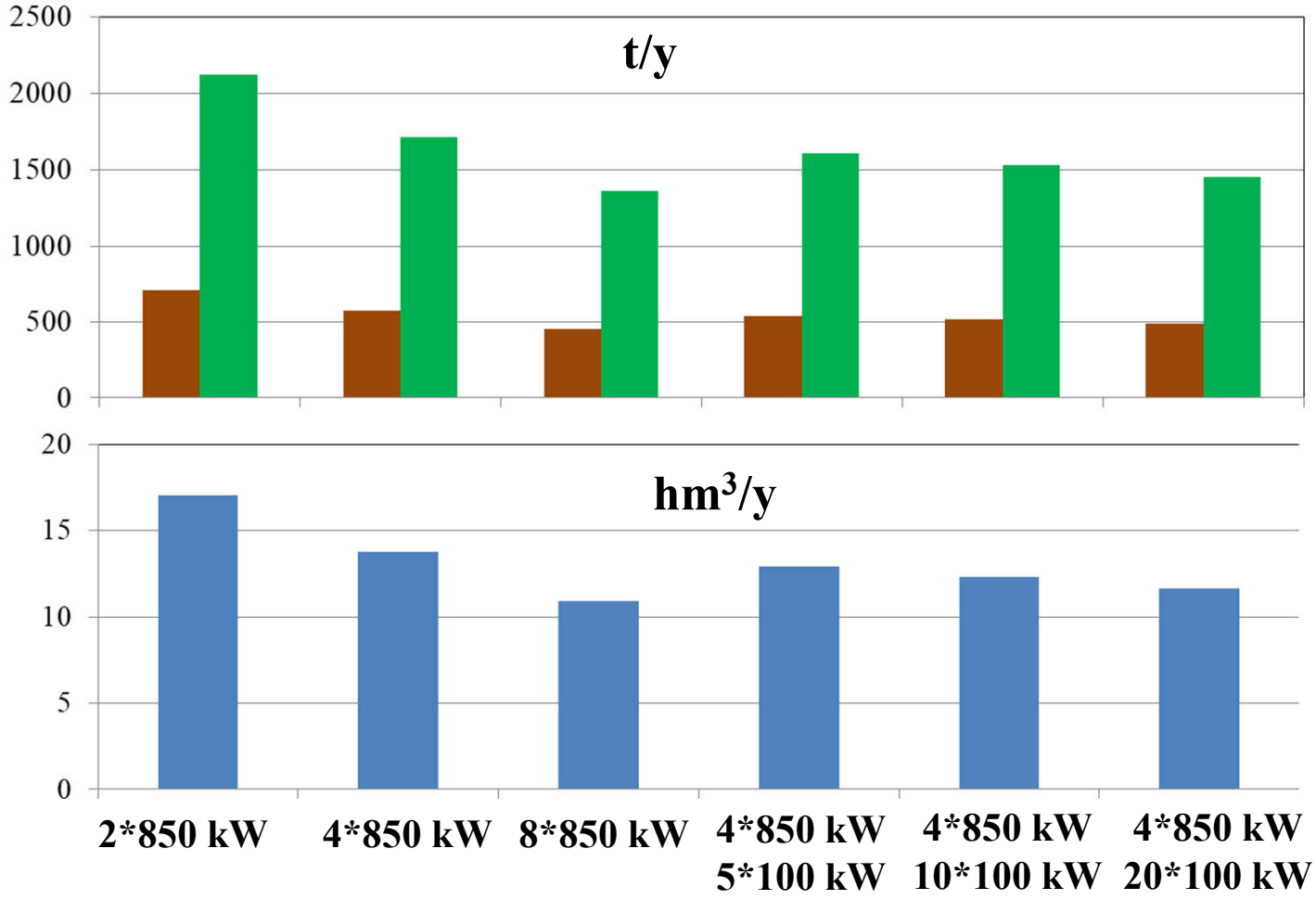
=(P2+P2*P5/100)*1*9,81/(P3*3600)

	M	N	O	P	Q	R	S	T	U
1			**Hydro**		**pump**				
2			Heigh m	100					
3			efficiency %	0,88					
4			kWh/m3	0,23	0,33	0,70			
5			Head Losses (%)	5					
6									
7			hm3/y	11,7		20,0			
8			I (MW)	2,44					
9			CF	0,12			max	83130998	
10							min	12482	
11									
12				To cover deficit		To store surplus		Initial Storage	
13				**Water (m3)**		**Water pumped (m3)**		80000	
14	**Deficit**	**Surplus**							
15	-0,66	0,00		2890		0		77110	
16	-0,45	0,00		1986		0		75124	
17	-0,39	0,00		1731		0		73392	
18	-0,40	0,00		1767		0		71625	
19	-0,44	0,00		1934		0		69691	
20	-0,38	0,00		1647		0		68044	
21	-0,12	0,00		537		0		67506	
22	-0,38	0,00		1665		0		65841	
23	-0,37	0,00		1642		0		64199	
24	-0,28	0,00		1207		0		62992	
25	0,00	0,03		0		86		63078	
26	0,00	0,44		0		1344		64422	
27	0,00	2,41		0		7399		71821	
28	0,00	2,98		0		9155		80976	

=N15*1000/$Q$4

=-M15*1000/$P$4

Basic water balance considering a reservoir

3-4. Covering energy deficits using other sources

	Oil	Biomass		Hydro
Calorific (kWh/kg)	12	4	Height (m)	86
Efficiency (%)	40	40	Efficiency (%)	0,85
Electric energy (MWh/t)	4,8	1,6	Electric energy (kWh/m^3)	0,20