Methodolgy to size a hybrid system

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Outline

- **Parameters to take into consideration**
- **Designing a load profile**
- **Study of the complementarity between solar and wind energy in a hybrid system**
- **Case study : Potou in Senegal**
- **Method to size hybrid PV-Wind-Batteries systems**
- **Applications**
- **Conclusion**

Parameters to take into consideration

Available potential

Complementarity between the available resources

Load profiles

Designing a load profile

Methodology

Household needs

- lighting
- audiovisual
- refrigeration

Public needs

- Schools
- clinics
- public lighting
- administrative offices

Business needs

- agriculture
- breeding
- trade
- Crop Conservation

Identification of main equipment and their operating periods

Consumption distribution during the day

Total hourly consumption of all devices

Load profile

Example

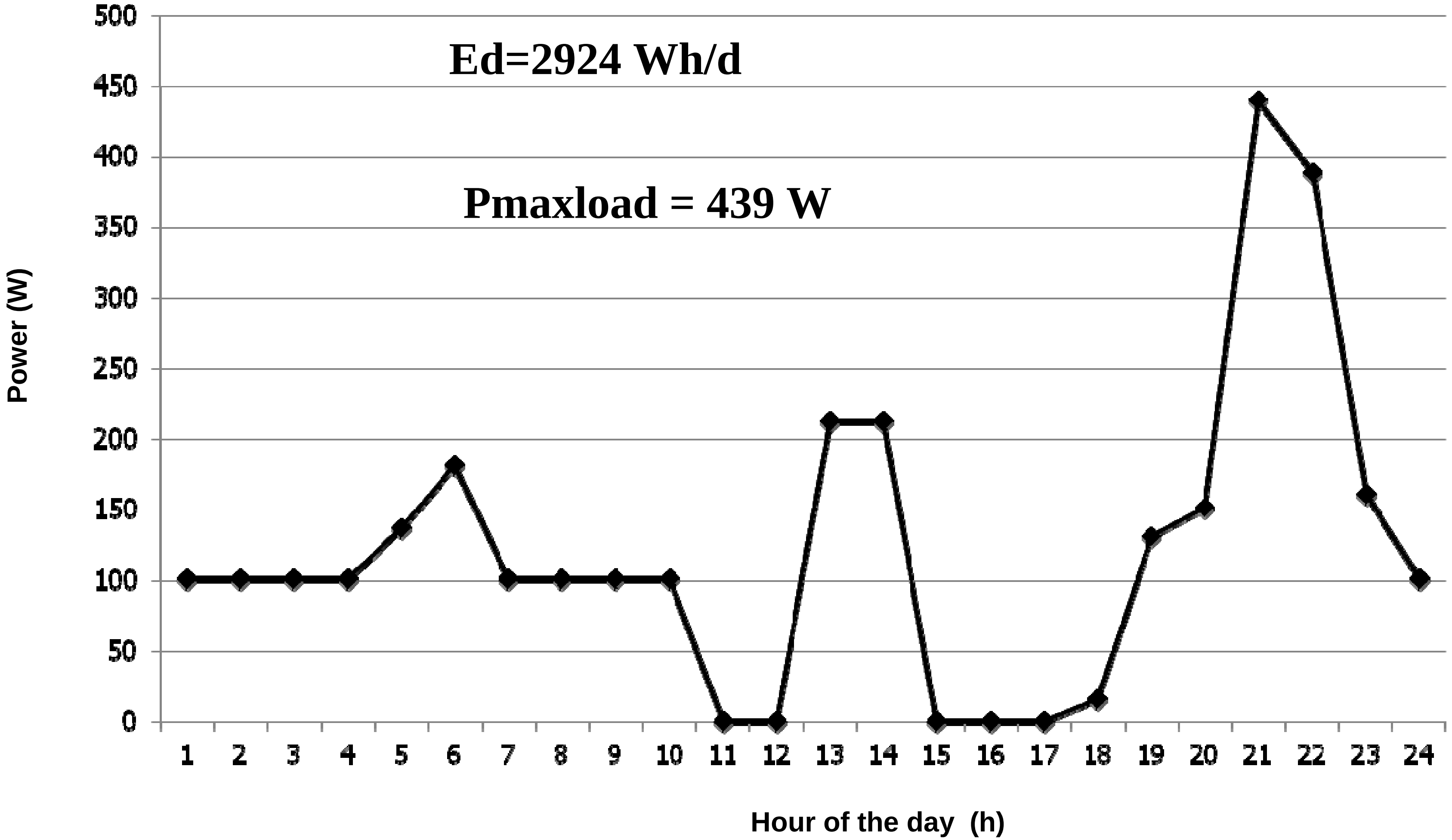
Designation	Power(W)	Number of devices	Total Power (W)	Duration of use (h)	Energy(Wh/d)
Lights					
Room 1 (R1)	36	1	36	3	108
Room2 (R2)	36	1	36	3	108
Room 3 (R3)	36	2	72	4	288
Toilet (R4)	15	2	30	2	60
Kitchen (R5)	15	1	15	4	60
Others					
Corlor TV	60	1	60	3	180
Radio	20	1	20	2	40
Refrigerator	100	1	100	16	1600
Fan	60	2	120	4	480
Total			**489**		**2924**

$P_{loadmax} = 489\ W$ $E_j = 2924\ Wh/d$

Load profile designing

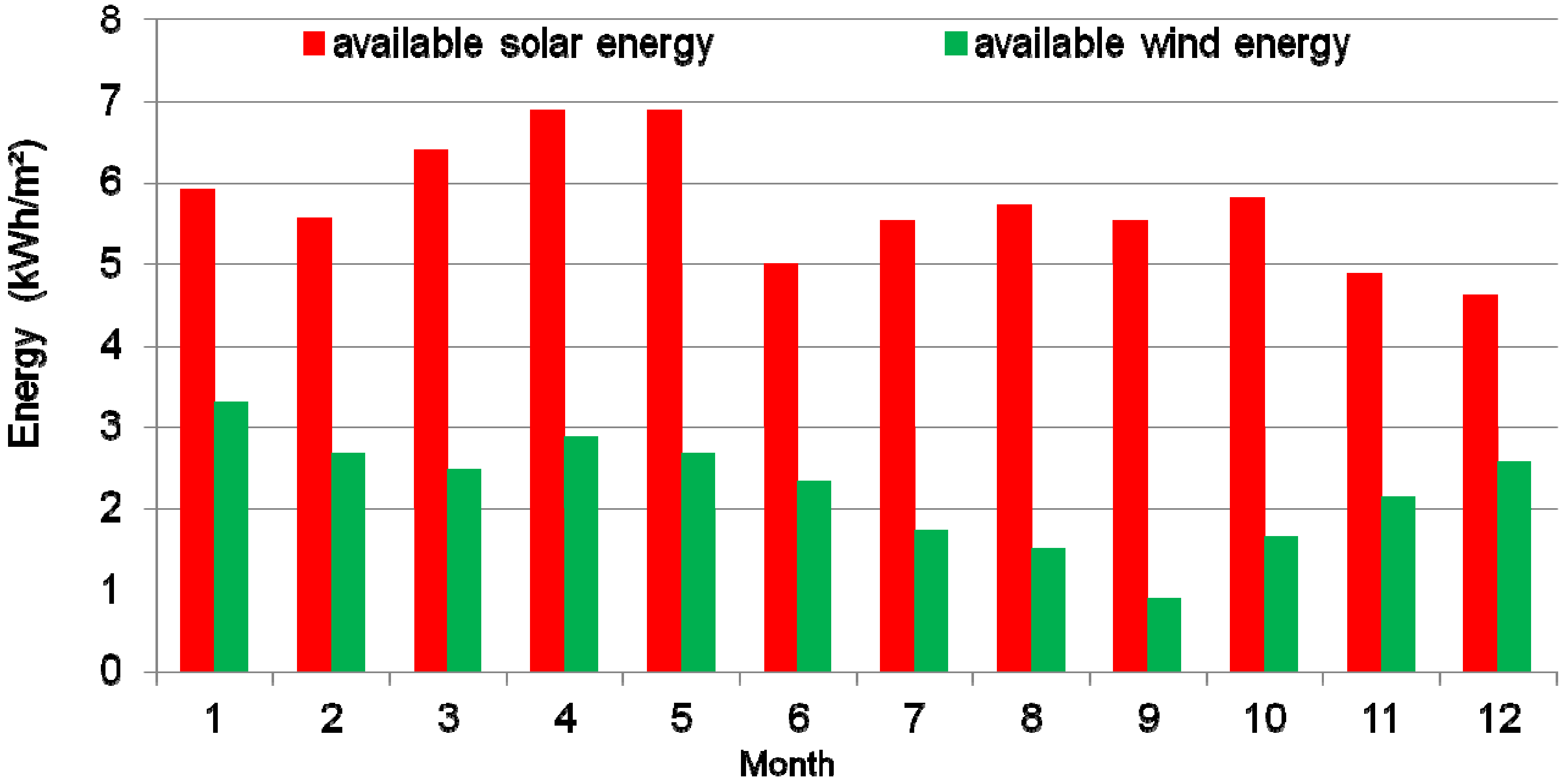
Time (h)	R1	R2	R3	R4	R5	TV	RC	RF	VT	PT(W)
1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
4	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
5	**0**	**36**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**136**
6	**36**	**0**	**0**	**30**	**15**	**0**	**0**	**100**	**0**	**181**
7	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
8	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
9	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
10	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
11	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
12	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
13	**0**	**0**	**0**	**0**	**0**	**0**	**20**	**0**	**120**	**140**
14	**0**	**0**	**0**	**0**	**0**	**0**	**20**	**0**	**120**	**140**
15	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
17	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18	**0**	**0**	**0**	**15**	**0**	**0**	**0**	**0**	**0**	**15**
19	**0**	**0**	**0**	**15**	**15**	**0**	**0**	**100**	**0**	**130**
20	**0**	**36**	**72**	**0**	**15**	**0**	**0**	**100**	**0**	**223**
21	**36**	**36**	**72**	**0**	**15**	**60**	**0**	**100**	**120**	**439**
22	**36**	**0**	**72**	**0**	**0**	**60**	**0**	**100**	**120**	**388**
23	**0**	**0**	**72**	**0**	**0**	**60**	**0**	**100**	**0**	**232**
24	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**0**	**100**
ET (Wh/d)	**108**	**108**	**288**	**60**	**60**	**180**	**40**	**1600**	**480**	**2924**

Load profile for a typical household

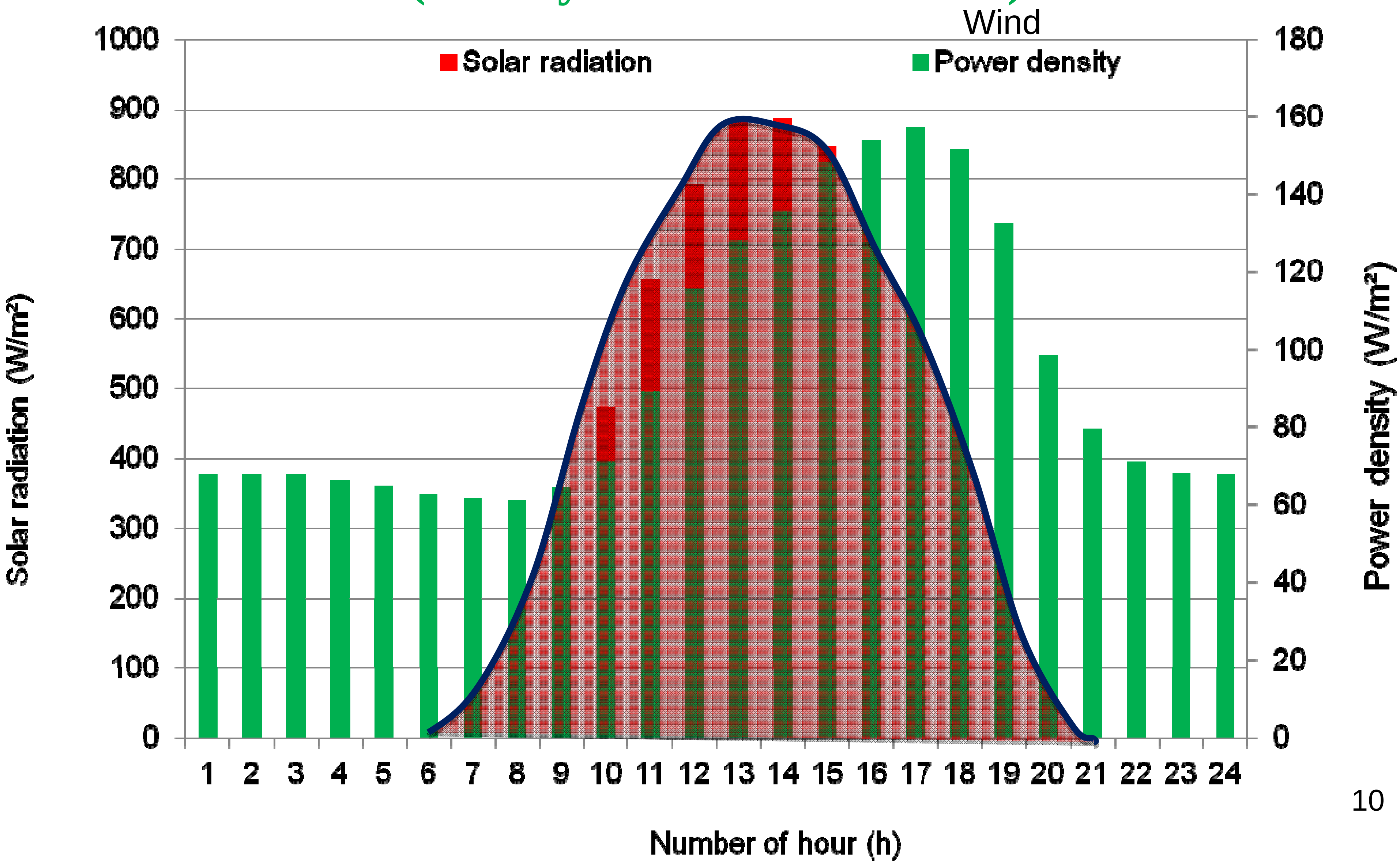


Study of the complementarity between solar and wind energy in a hybrid system

Complementarity between solar and wind energy potential (Example of Potou)



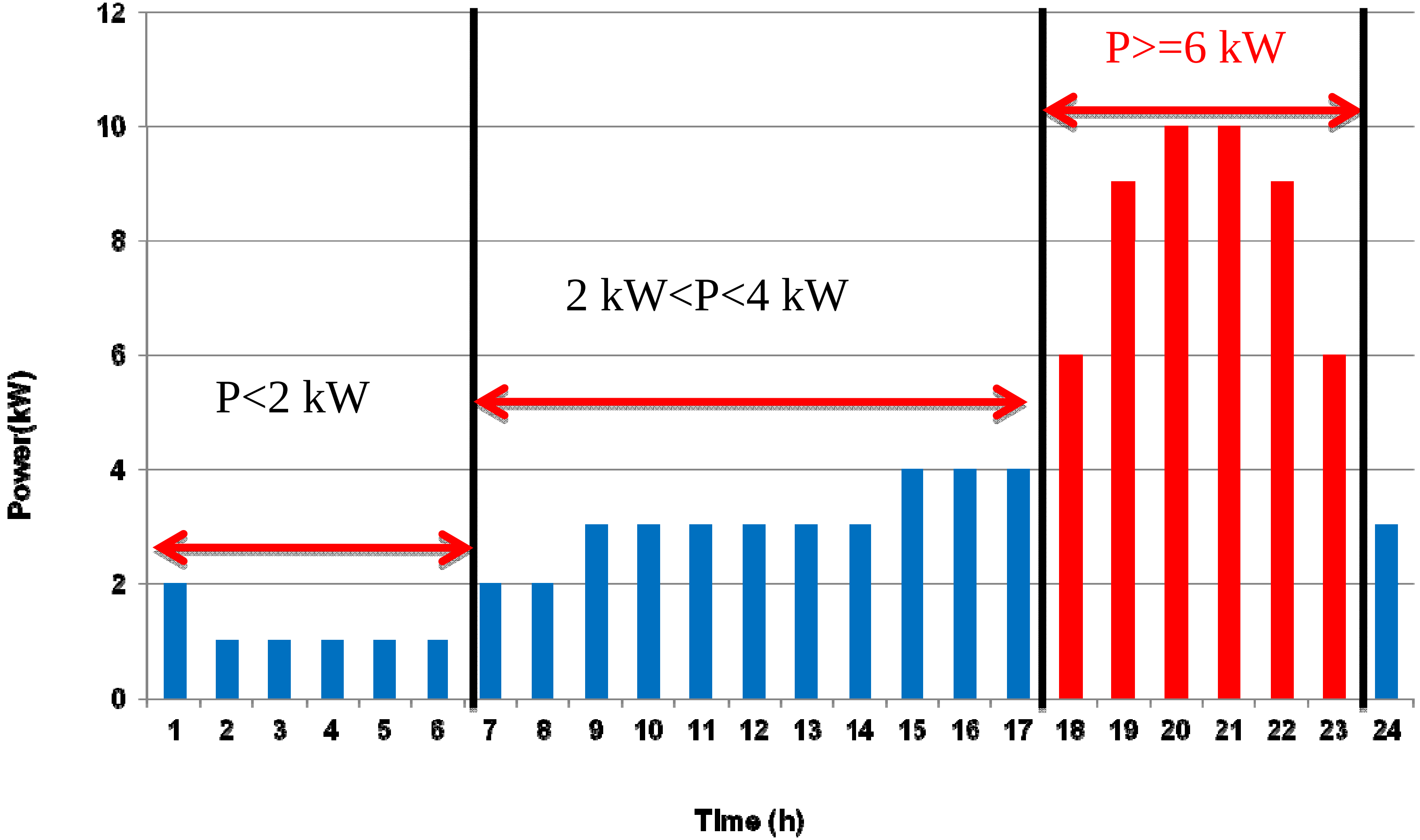
Complementarily between solar and wind potential (Hourly variation in Potou)



Case study : Potou

Example of load profile

Load profile for 950 inhabitants, divided into 75 households



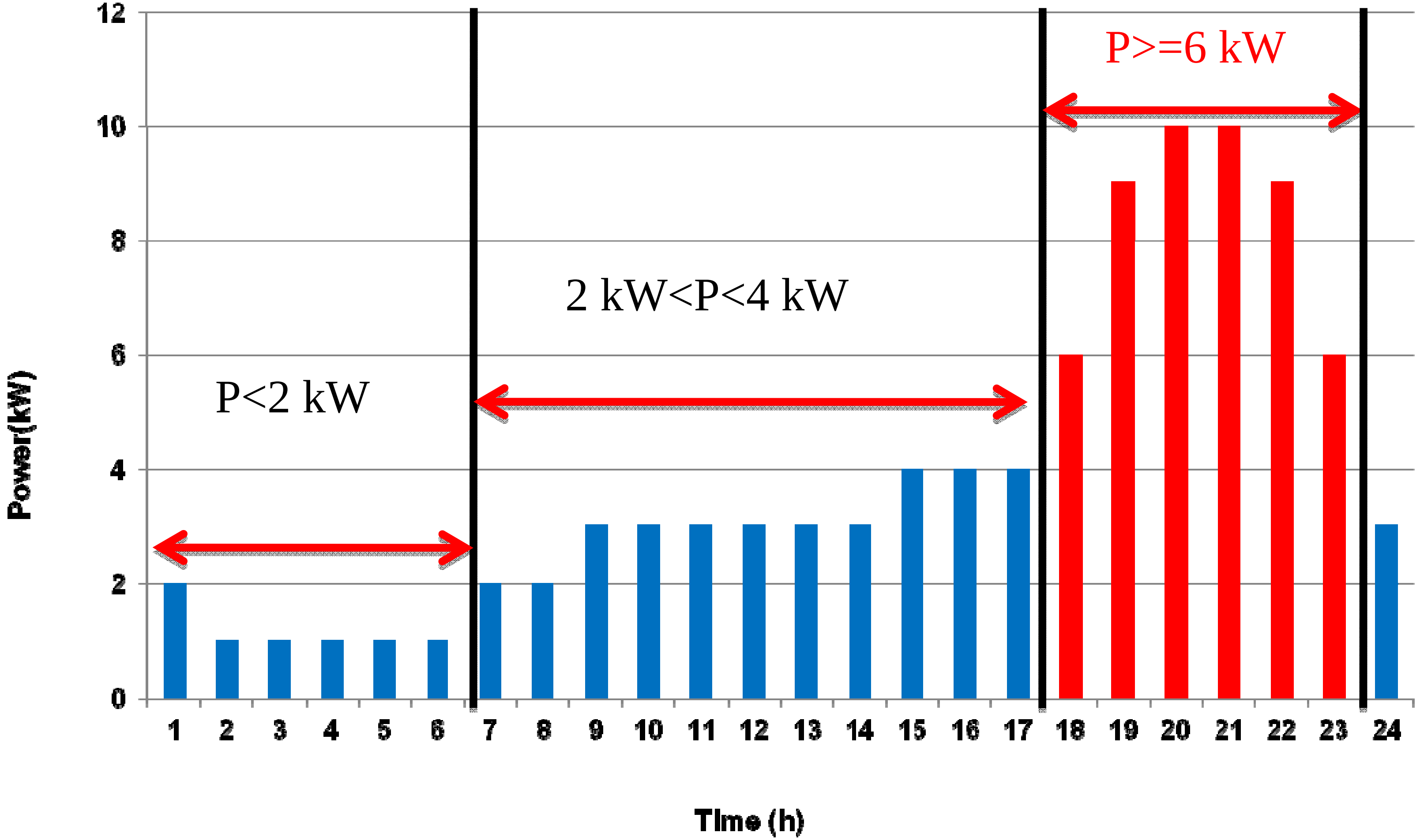
Consumption

- Pumping
- Rerigerators
- Mills
- Radios
- Televisions

Peak power = 10 kW observed at 20h-21h
Total energy required : Ej=94 kWh/j

Example of load profile

Load profile for 950 inhabitants, divided into 75 households



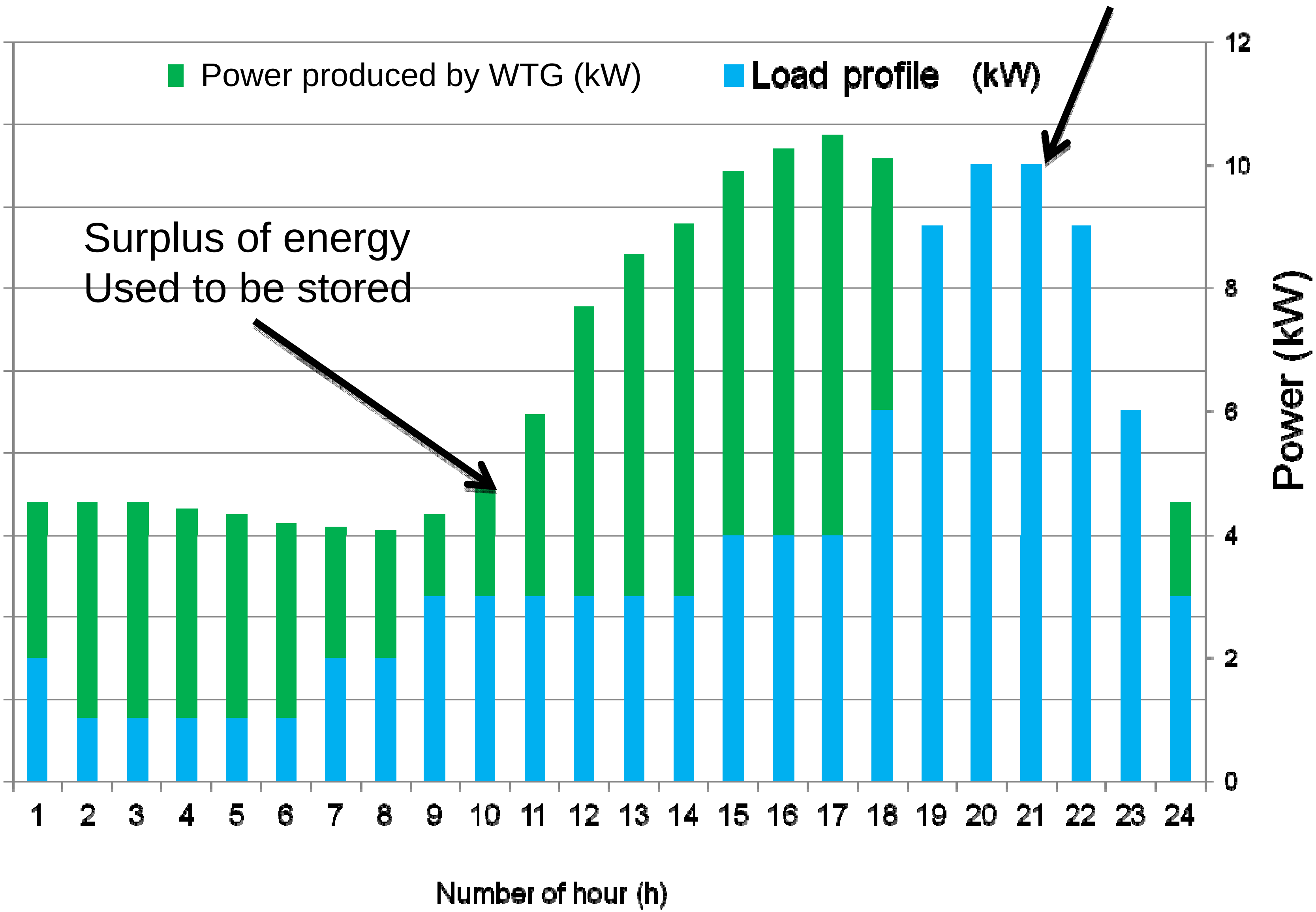
Consumption

- Pumping
- Rerigerators
- Mills
- Radios
- Televisions
- **Lighting**

Peak power = 10 kW observed at 20h-21h

Total energy required : Ej=94 kWh/j

No cover load profile



EUROPEAN UNION ENERGY INITIATIVE for poverty eradication and sustainable development

JRC EUROPEAN COMMISSION

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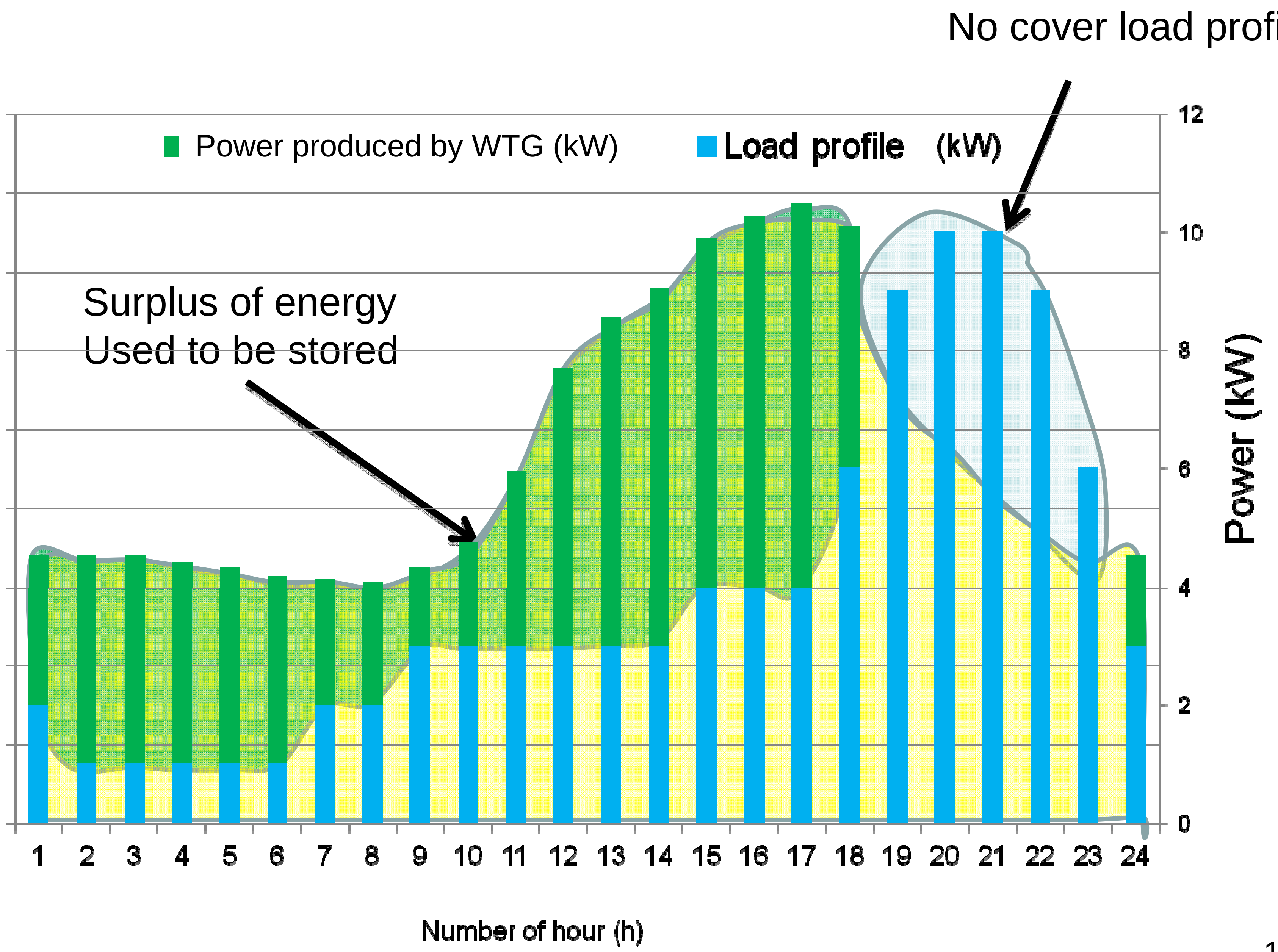
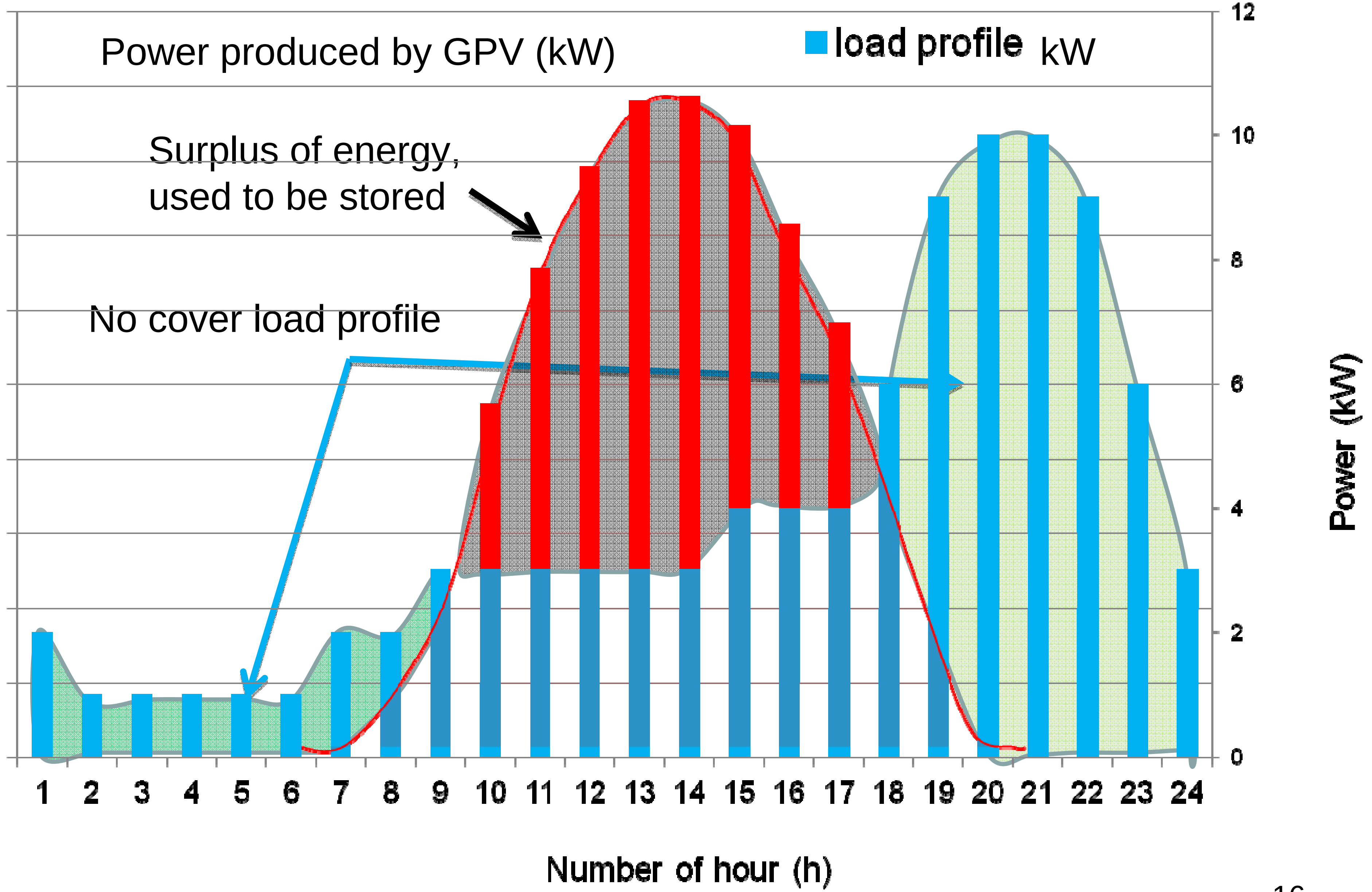
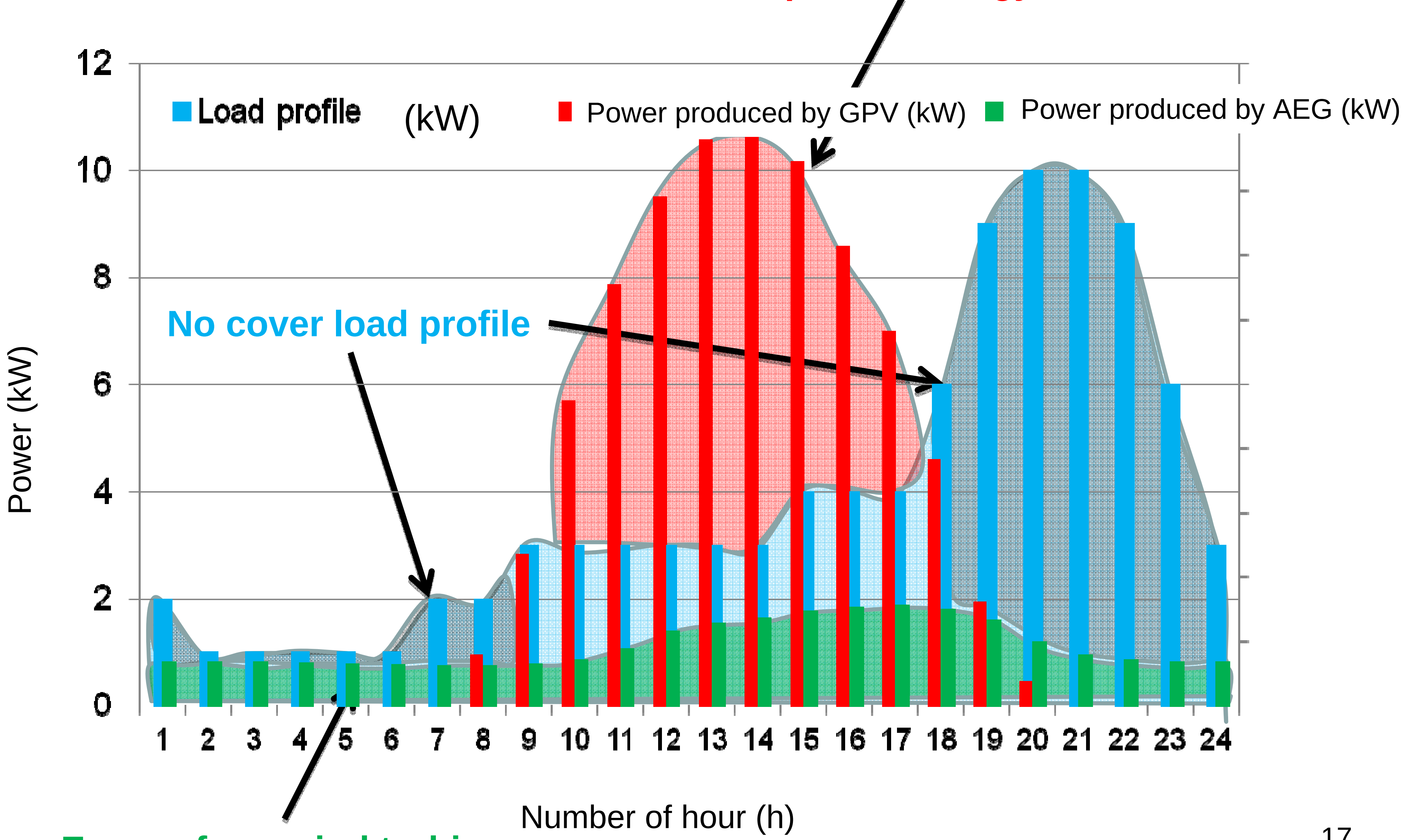



Power produced by GPV (kW)
load profile kW
Surplus of energy, used to be stored
No cover load profile
Power (kW)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Number of hour (h)

Surplus of energy used to be stored



Energy from wind turbine

Method to size hybrid PV-Wind-Batteries systems

A hybrid energy system is a system that combines two or more energy sources for generating electricity to be injected into a grid or to be used for remote locations.

There are several configurations :

- Wind-solar
- Wind-solar-battery
- Diesel generator-solar-battery
- Diesel generator-wind-battery
- Diesel generator-wind-solar-battery

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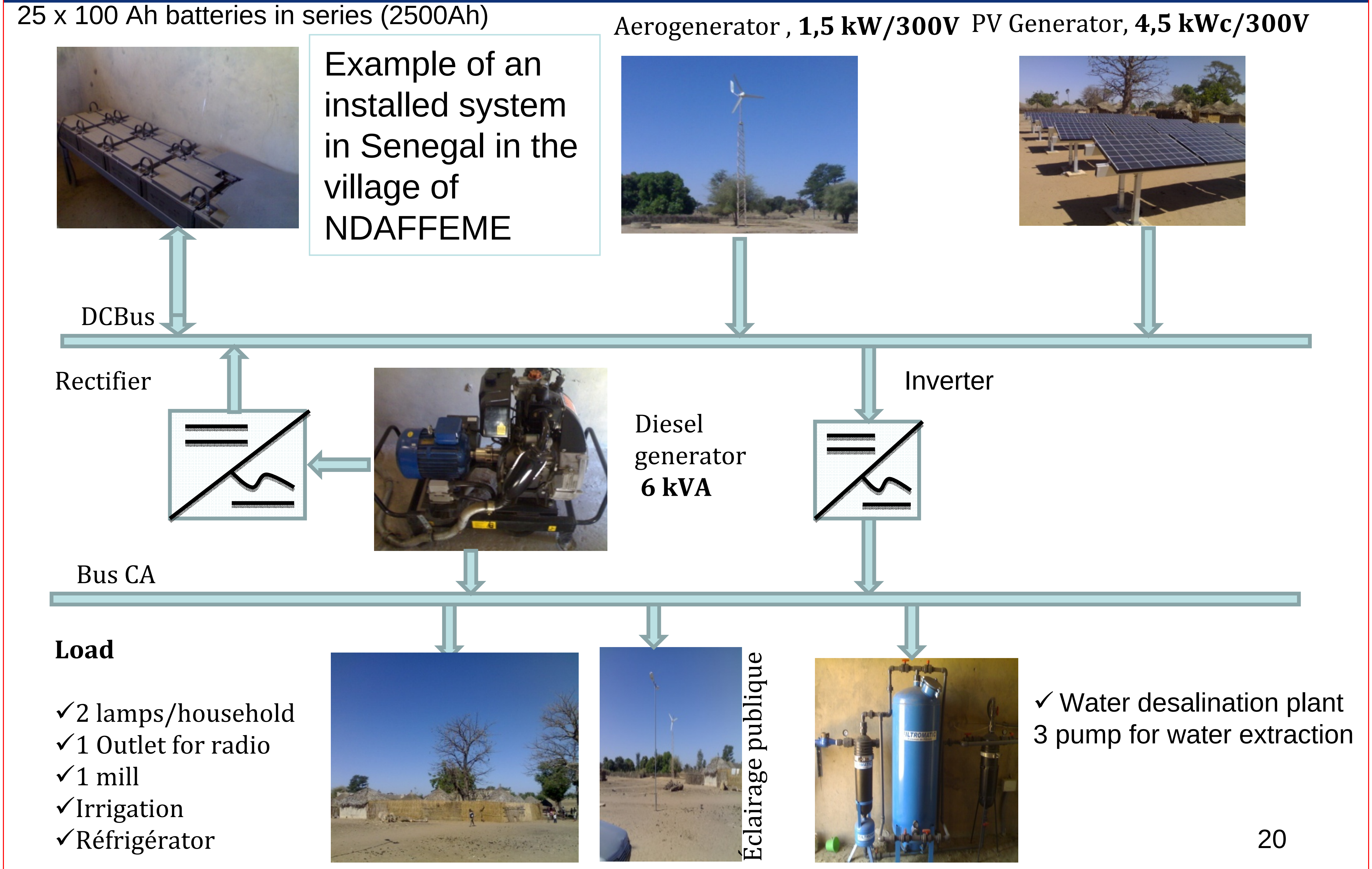
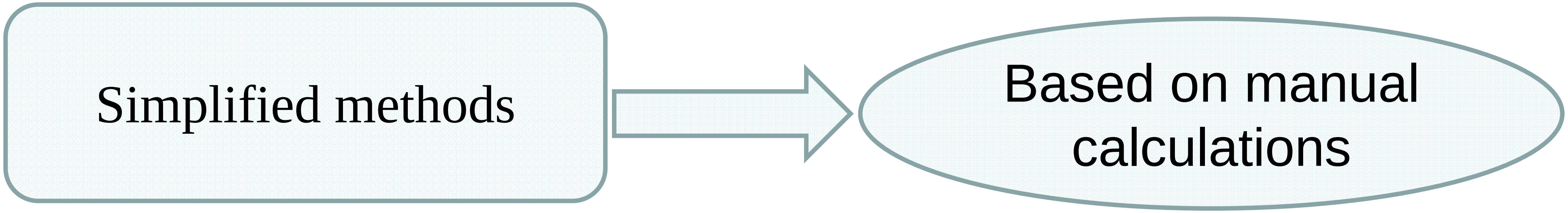
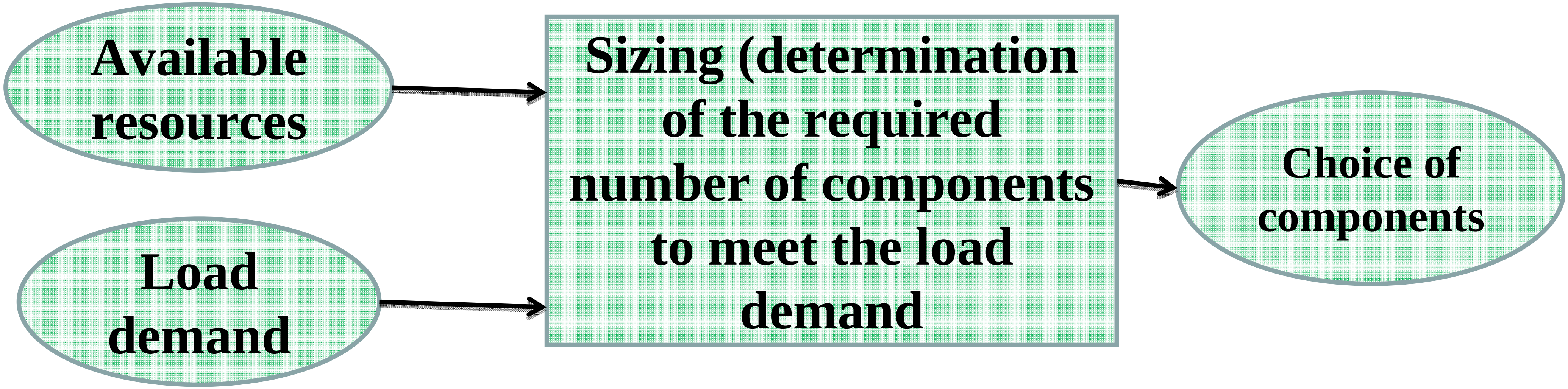


Method to size hybrid PV-Wind-Batteries systems





Simplified method:
Sizing of hybrid PV-Wind-Batteries system

Methodology :

- Sizing of each source based on the available potential
- Determination of the battery capacity able to meet the load demand in case of sources production failure.
- Selecting the other components (charge controller, inverter, ...)

Sizing PV modules

$$P_{gpv} = \frac{E_d}{I_{rr} \cdot \eta_{bat} \cdot \eta_{inv} \cdot \eta_{reg} \cdot k_p} \cdot fs$$

$$N_{tpv} = \frac{P_{gpv}}{P_c}$$

$$N_{se} = \frac{U_n}{U_{pv}}$$

$$N_{pp} = \frac{N_{tpv}}{N_{se}}$$

$$f_s = \frac{I_{rr}}{I_{rr} + E_w}$$

P_{gpv} : Power of the solar generator to be installed (W)
Pc: module Peak power (Wc)
I_{rr} : Solar radiation (Wh/m²/d)
η_{bat} : efficiency of batteries (%)
η_{inv}: converter efficiency (%)
η_{reg} : regulator efficiency (%)
k_p : loss coefficient due to cables (%)
E_d: daily demand (Wh/d)
f_s : fraction of available solar energy (%)
E_w: available wind energy (Wh/m²/d)
U_s : main system voltage (V)
U_{pv} : module nominal voltage (V)

N_{pp} : number of PV modules to be in parallel
N_{tpv} : total number of PV modules
N_{se} : number of PV modules to be in series

sizing wind turbine generator

$$P_e = \frac{E_d}{F_c \cdot R_g . N_h} \cdot f_e$$

$$N_{el} = \frac{P_e}{P_n}$$

$$f_e = \frac{E_w}{I_{rr} + E_w}$$

E_d: daily demand (Wh/d)
Pe : total wind turbine power to be installed (W)
Pn : nominal power of one wind turbine (W)
Fc : Capacity factor of each wind turbine (%)
fe : fraction of available wind energy in the site (%)
Nh : number of hours a day (h)
Rg : wind turbine system overall efficiency (%)

Nel : number of wind turbines to be installed

Sinzing of Battery capacity

$$C_n = \frac{N_{aut} \cdot E_d}{P_d \cdot U_s \cdot \eta_{bat} \cdot \eta_{inv} \cdot \eta_{reg} \cdot k_p}$$

E_d: daily demand (Wh/d)
N_{aut} : number of day of autonomy (d)
P_d : battery discharge depth (%)
η_{bat} : efficiency of batteries (%)
$\eta_{inv:}$ converter efficiency (%)
η_{reg} : regulator efficiency (%)
k_p : loss coefficient due to cables (%)

C_n : nominal capacity of storage system (Ah)

Sizing regulator and inverter

regulator

$$I_{rgt} >= N_{pp} \cdot I_{cc}$$

inverter

$$P_{inv} = \frac{P_{\max load} + P_{loss}}{n_{inv}}$$

P_{inv} : inverter nominal power (W)
U_s : system nominal voltage (V)
$P_{maxload}$: maximum load power (W)
I_{rgt} : regulator nominal current (A)
I_{cc} : PV modules short-circuit current (A)
N_{pp} : number of PV modules to be in parallel
P_{loss} : Power related to the unexpected load (W)

Limits of the simplified method

- **Based on the analytic and simple relations (Over sizing or under sizing of the system)**
- **Variations of parameters like solar energy potential , wind energy potential are not considered**

Improved method

↓

Based on the use of software

HOMER
The Micropower Optimization Model

Hybrid Optimisation Model Electric Renewable

HOMER
The Micropower Optimization Model

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- Simulation (test on several configurations)
- Optimisation (choosing the best configuration that optimizes the cost of the system)
- Sensitivity analysis (influence study of some parameters variation on the optimal configuration e.g potential, LPSP, …)

Advantages of Homer:

- New sizing approach ;
- Allows an optimal configuration to be defined.

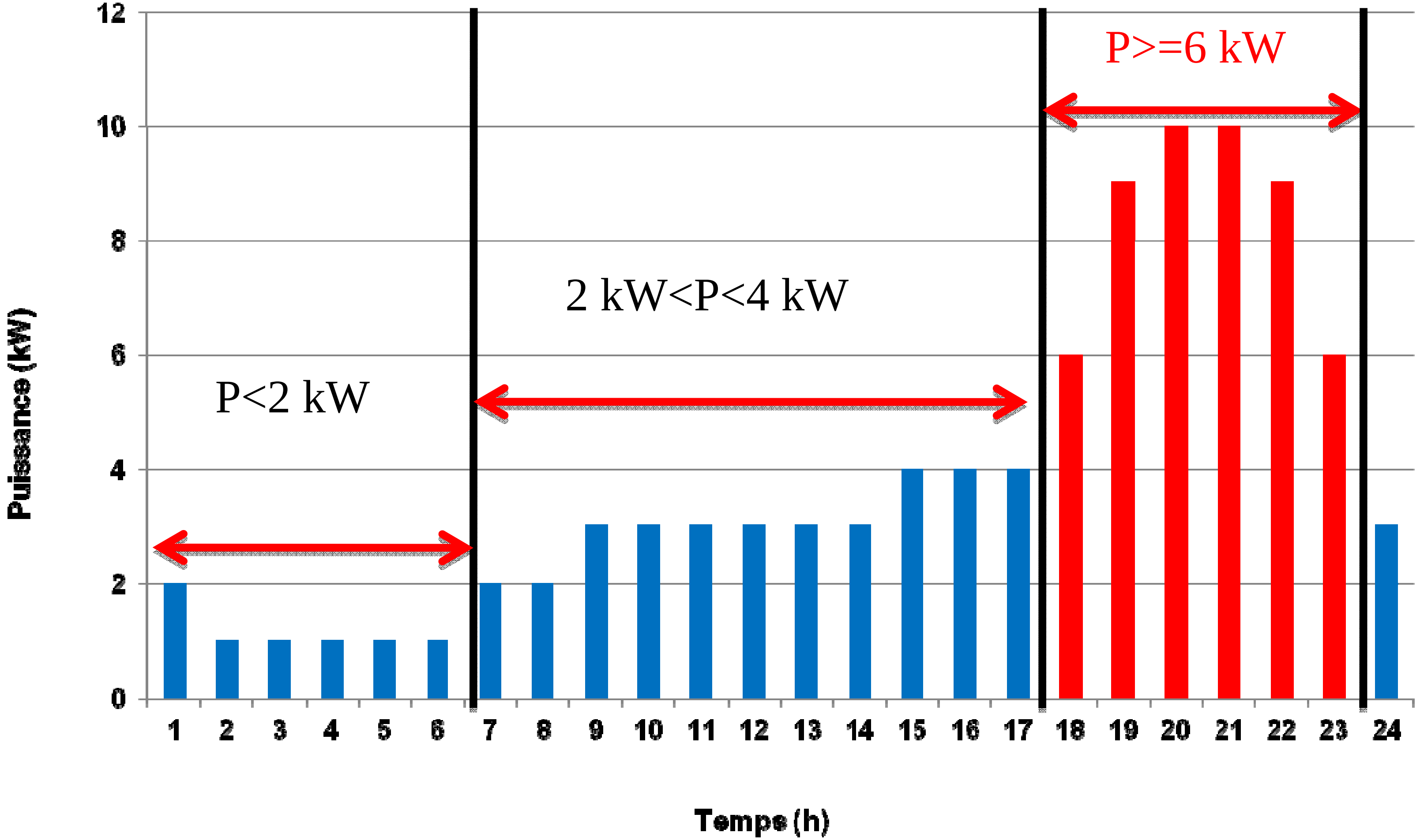
Limits :

- Does not allow multi-objective optimization (one parameter variation) to carried out;
- Uses the parameters mean (e.g. wind speed, solar radiation,….)

Applications

Example of load profile

Load profile for 950 inhabitants, divided into 75 households



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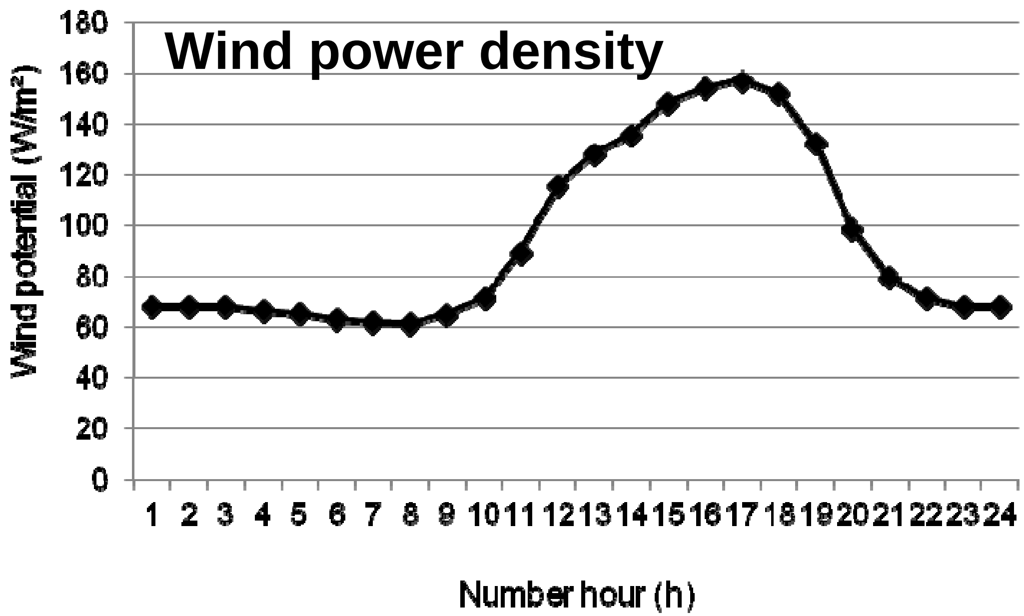
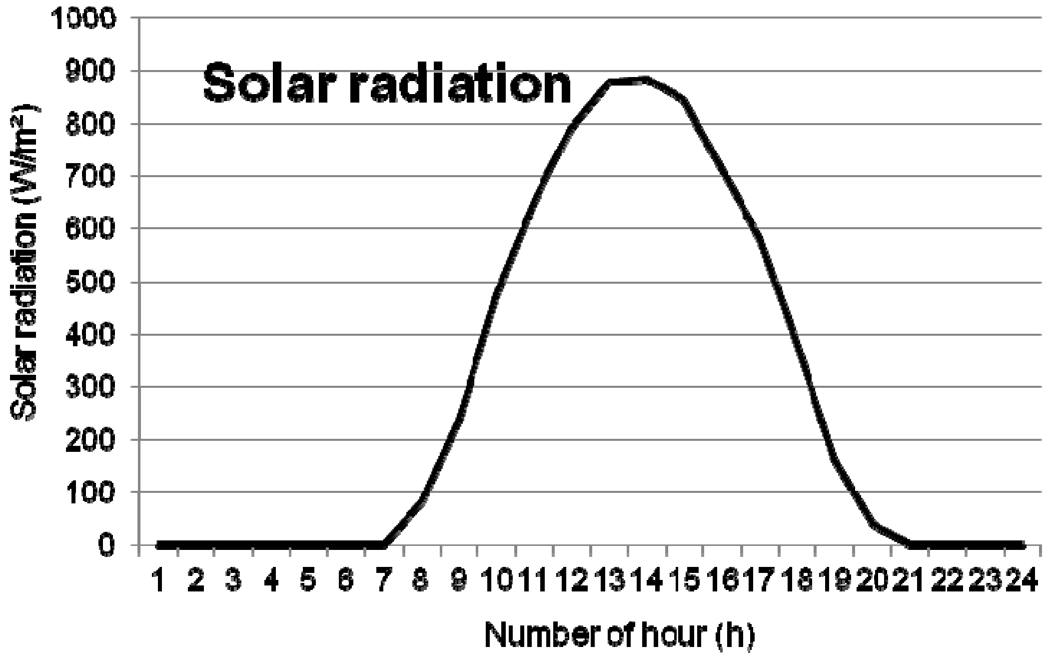
Site of Potou



Mean available wind energy

E_w=2250 Wh/m²/d

fe= 25%



Mean available solar energy

I_{rr}=6717 Wh/m²/d

fs=75%

Example of components specifications

Type of wind Turbine	Elosenegal/500W/24
Cut-in speed ¶(m/s)	3
Nominal speed (m/s)	7
Maximum speed (m/s)	10
Nominal power (W)	500
Nominal voltage (V)	24
Cost (Euro)	1 077
Type of module PV	P (150W/24V)
Rate voltage (V)	24
Voltage of open circuit (V)	43.4
Current of short-circuit ¶(A)	4.7
Power peak (W)	150
Fill factor	0.74
Cost (Euro)	900
Type of battery	(C20) - FG2F009
Nominal voltage of battery (V)	12
Nominal capacity ¶ (Ah)	150
Cost (Euro)	285
Type of regulator	REGTARGOM430
Nominal current (A)	40
Nominal voltage (V)	48
Cost (Euro)	398
Type of inverter	SINWAVE
Nominal Power (W)	3 500
Nominal voltage (V)	48
Cost (Euro)	2 799

Tableau V. 2 : Used parameters in the sizing

Number of day of autonomy	3 days
Depth of discharge	50 %
Voltage of the system	48 V
Efficiency of one battery	70 %
Efficiency of the inverter	80 %
Efficiency of the regulator	85 %
loss coefficient due to cables kp	95 %
Lifetime of the battery	5 years
Lifetime of the inverter	10 years
Lifetime of the regulator	10 years
Lifetime of the system	20 years
Capacity factor of the Wind turbine on the site	33 %
Solar radiation on the site	6,72 kWh/m²/d
Available wind energy	2.23 kWh/m²/d
Loss of Power supply probability	0 %

Configurations obtained with the use of simplified and improved methods, considering 0 % of the Loss of Power Supply Probability (LPSP)

Method	Number of Modules PV	Number of Wind turbine	Number of Batteries	Nomber of regulators	Nomber of inverters	Annualized Cost System (million of euro)
SM	128	88	112	8	6	0,164
Homer	268	20	136	16	7	0,184

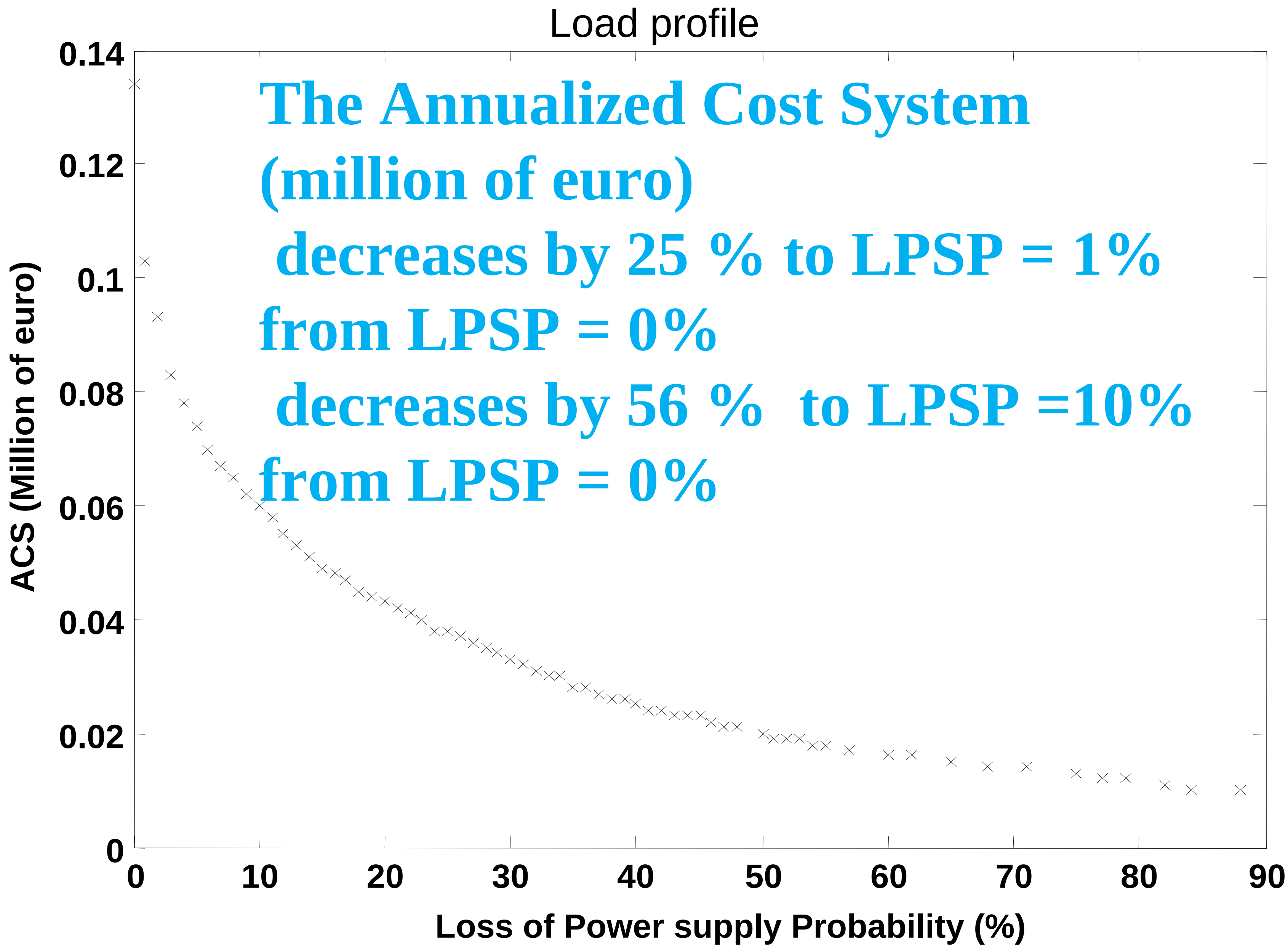
Other new probabilistic methods (i.g Genetic Algorithm (AG)) are available and allow an optimal hybrid Solar wind-batteries system minimizing the cost and the LPSP to be sized by fixing the system management constraints (Power supply, state of charge of the batteries, …).

Influence of the method used on the optimal configuration

Three configurations for the LPSP equal to 0 % (a total supply of the load profile)

Method	Number of Modules PV	Number of Wind turbine	Number of Batteries	Nomber of regulators	Nomber of inverters
MS	128	88	112	8	6
Homer	268	20	136	16	7
AG	110	41	160	7	6

Influence of the LPSP on the optimal configuration



The Annualized Cost System (million of euro)

decreases by 25 % to LPSP = 1% from LPSP = 0%

decreases by 56 % to LPSP =10% from LPSP = 0%

Conclusion

Sizing a hybrid system solar-wind-battery can be carried out with methods ensuring a cover total of the load, which implies an oversizing of the system.

The use of probabilistic methods can bring an optimal configuration minimazing the system cost.
Example : genetic algorithm with the introducing of the loss of power supply probability (LPSP))

Thank you