DOMESTIC STORAGE AND SOLAR POWER

A BIG-DATA BASED OPTIMIZATION OF THE ELECTRICITY BILL

JOSÉ MIGUEL LEIVA MURILLO

A CRASH COURSE ON THE SPANISH ELECTRICITY BILL

DETALLE DE LA FACTURA

LUZ

Importe por potencia contratada:

4,6 kW x 0,121292 Eur/kW x 7 días		3,91 €
4,6 kW x 0,121292 Eur/kW x 42 días		23,43 €
4,6 kW x 0,120961 Eur/kW x 17 días		9,46 €
En dicho importe, facturación por peaje de acceso:		
4,6 kW x 38,043426 Eur/kW y año x (7/365) días	3,36 €	
4,6 kW x 38,043426 Eur/kW y año x (42/365) días	20,14 €	
4,6 kW x 38,043426 Eur/kW y año x (17/366) días	8,13 €	
		36,80 €

Importe por energía consumida:

235 kWh x 0,135247 Eur/kWh		31,78 €
82 kWh x 0,133681 Eur/kWh		10,96 €
En dicho importe, su facturación por peaje de acceso ha sido:		
33 kWh x 0,044027 Eur/kWh	1,45 €	
202 kWh x 0,044027 Eur/kWh	8,89 €	
82 kWh x 0,044027 Eur/kWh	3,61 €	
		42,74 €

SUBTOTAL	**79,54 €**

OTROS CONCEPTOS

DESCUENTOS (5,00)% x 36,80	-1,84 €
. % DTO. PROMOCIONAL 5,00 %	
% Dto. Promo. s/ potencia 36,8 Eur x -5 %	-1,84 €
Impuesto electricidad (75,86 X 5,11269632 %)	3,88 €
Alquiler equipos de medida y control (66 días x 0,026666 Eur/día)	1,76 €
SUBTOTAL	**1,96 €**
Importe total	**81,50 €**
IVA NORMAL (21%) 21% s/ 81,50	17,12 €
TOTAL IMPORTE FACTURA	**98,62 €**

DESTINO DEL IMPORTE DE LA FACTURA

El destino del importe de su factura, 98,62 euros, es el siguiente:

- Impuestos aplicados
- Coste de producción de electricidad
- Costes Regulados

Incentivos a las energías renovables, cogeneración y residuos	19,59 €
Coste de redes de transporte y distribución	19,94 €
Otros costes regulados (incluida la anualidad del déficit)	12,54 €

A los importes indicados en el diagrama debe añadirse, en su caso, el importe del alquiler de los equipos de medida y control así como los conceptos no energéticos.

WITNESSING A REVOLUTION

STORE MORE

Elon Musk thinks Tesla can sell batteries much faster than cars

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By John Parnell | Mar 26, 2014 1:49 PM GMT | 0

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INDUSTRIA PUBLICA EN EL BOE LA NUEVA TARIFICACIÓN

¿Cómo funciona la nueva tarifa eléctrica por horas?

Entra en vigor el 1 de julio, aunque las eléctricas tienen hasta octubre para adaptarse

Operational cost optimization for renewable energy microgrids in Mediterranean climate

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***Abstract*—This paper is concerned with the energy management of a micro-grid composed of photovoltaic/ wind/ diesel sources used to supply household loads. The control strategy manages the power flow between the power sources and the loads, which ensures the minimization of the installation operating cost, the safe operating for the battery bank while minimizing the use of the diesel engine. The strategy is tested using measured data of some climatic parameters of a Mediterranean area (Northern Tunisia), showing its efficiency in fulfilling the fixed objectives and respecting the criteria of the**

power supply and a safe operation for the battery bank, by considering the powers P_{pv}, P_w, P_{bat} and P_G, generated by the photovoltaic panels, the wind turbine, the battery bank and the diesel engine, respectively (*Fig.*2).

In fact, the strategy consists in evaluating, at each sample time, the optimum power sources combination, thus minimizing the power production costs and supplying the loads continuously, and guaranteeing a safe operation for the

IS IT POSSIBLE TO LIVE *OFF-GRID* ?

Operational cost optimization for renewable energy microgrids in Mediterranean climate

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***Keywords*—renewable energies; diesel engine; cost optimization; microgrids; autonomy**

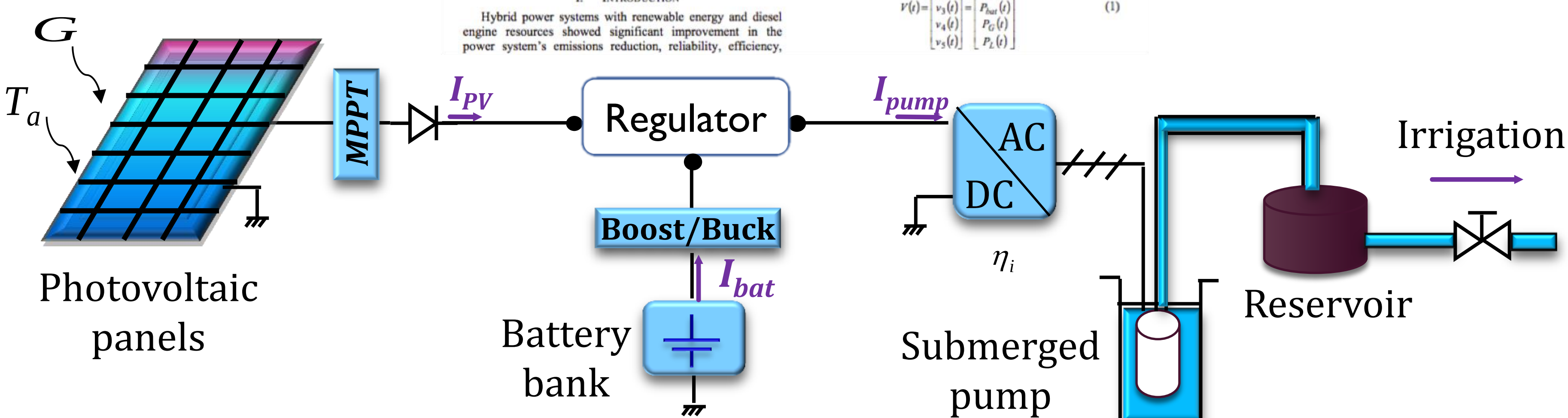
I. INTRODUCTION

Hybrid power systems with renewable energy and diesel engine resources showed significant improvement in the power system's emissions reduction, reliability, efficiency,

power supply and a safe operation for the battery bank, by considering the powers P_{pv}, P_w, P_{bat} and P_G, generated by the photovoltaic panels, the wind turbine, the battery bank and the diesel engine, respectively (*Fig.*2).

In fact, the strategy consists in evaluating, at each sample time, the optimum power sources combination, thus minimizing the power production costs and supplying the loads continuously, and guaranteeing a safe operation for the battery bank (*Fig.* 3). Indeed, the system is composed of five components that reflect the fives energy sources: it is described as follows:

$$V(t)=\begin{bmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \\ v_4(t) \\ v_5(t) \end{bmatrix}=\begin{bmatrix} P_{PV}(t) \\ P_W(t) \\ P_{bat}(t) \\ P_G(t) \\ P_L(t) \end{bmatrix} \quad (1)$$



IS IT POSSIBLE TO LIVE *OFF-GRID* ?

- The estimation of the solar radiation is an complex problem

❖ Global insolation (Liu & Jordan model):

$$H(t,d) = \frac{\pi}{24}\frac{\cos w - \cos w_s}{\sin w_s - w_s \cos w_s}\left(0.409 + 0.501\sin\left(w_s - \frac{\pi}{3}\right) + \left(0.6609 + 0.4767\cos\left(w_s - \frac{\pi}{3}\right)\right)\cos w\right)\overline{H}$$

❖ Diffused solar radiation

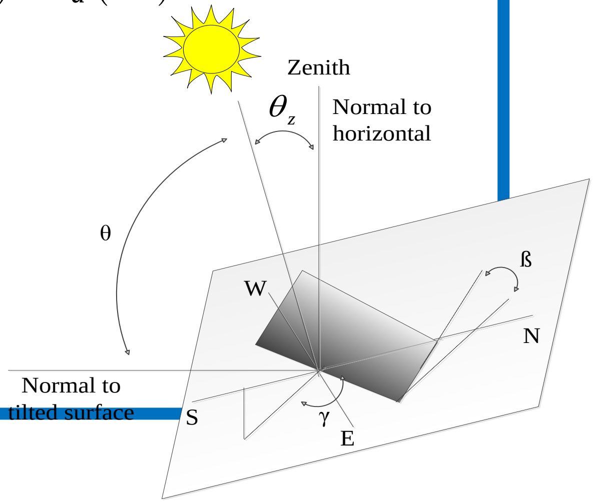
$$H_d(t,d) = \frac{\pi}{24}\frac{\cos w - \cos w_s}{\sin w_s - w_s \cos w_s}\overline{H_d}$$

❖ Direct solar radiation

$$H_b(t,d) = H(t,d) - H_d(t,d)$$

❖ Solar radiation on a tilted panel

$$G(t,d) = R'_b\, H_b(t,d) + \left(\frac{1+\cos\beta}{2}\right) H_d(t,d) + \rho\left(\frac{1-\cos\beta}{2}\right) H(t,d)$$



Source: Yahyaoui et al., *Operational Cost Optimization for Renewable Energy Microgrids*

IS IT POSSIBLE TO LIVE *OFF-GRID* ?

- … and also the problem of estimating the panel's yield.

The model used for sizing the PVP is based on the photovoltaic module yield:

Photovoltaic yield

$$\eta_{pv}(t) = \eta_r (1 - \beta_{pv}(T_c(t) - T_{ref}))$$

Cell temperature

$$T_c(t) = T_a(t) + G(t,d)\frac{NOCT - T_{ref}}{800}$$

Photovoltaic power

$$P_{pv}(t) = S\, G(t,d)\, \eta_{pv}(t)$$

η_r : panel yield at the reference temperature T_{ref}

β_{pv} : temperature coefficient for the panel yield

T_a : ambient temperature

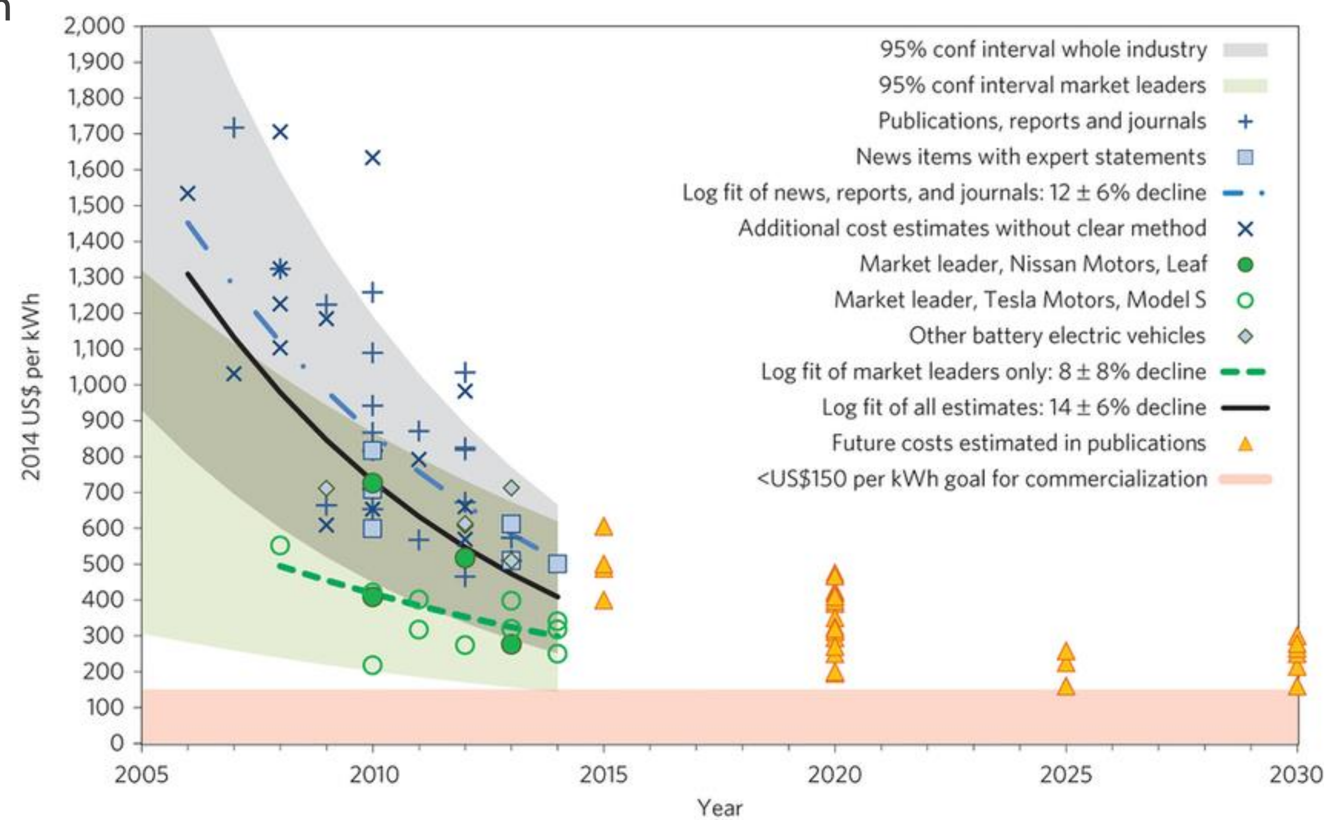
$NOCT$: Normal Operating Cell Temperature

S : panel surface

Source: Yahyaoui et al., *Operational Cost Optimization for Renewable Energy Microgrids*

DOMESTIC STORAGE: A GOOD OPTION ALREADY

- The cost of storing energy in a Lithium battery is reported to be around 15 cts/kWh



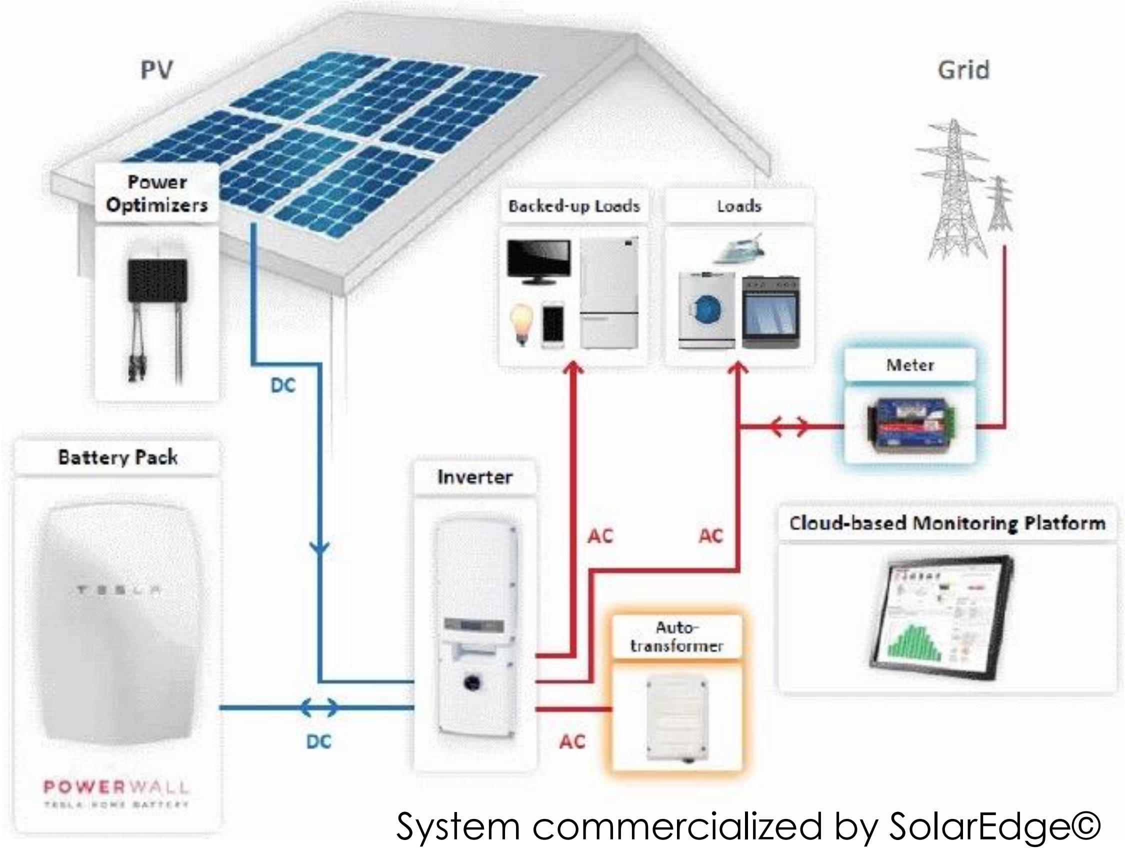
Source: B. Nykvist and M. Nilsson, Rapidly falling costs of battery packs for electric vehicles, *Nature Climate Change*, 2015

HAS SOLAR POWER REACHED GRID-PARITY?

"*Unsubsidized rooftop solar electricity costs between $0.08-$0.13/kWh, 30-40% below retail price of electricity in many markets globally*". Deutsche Bank report: Solar grid parity in a low oil price era, March 2015

THE TECHNOLOGY IS ALREADY HERE…

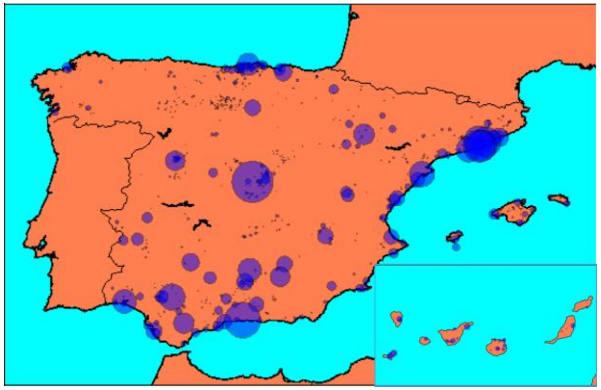
Intelligent system: many degrees of freedom!



System commercialized by SolarEdge©

BIG DATA AND WHERE TO FIND THEM

Endesa Dataset



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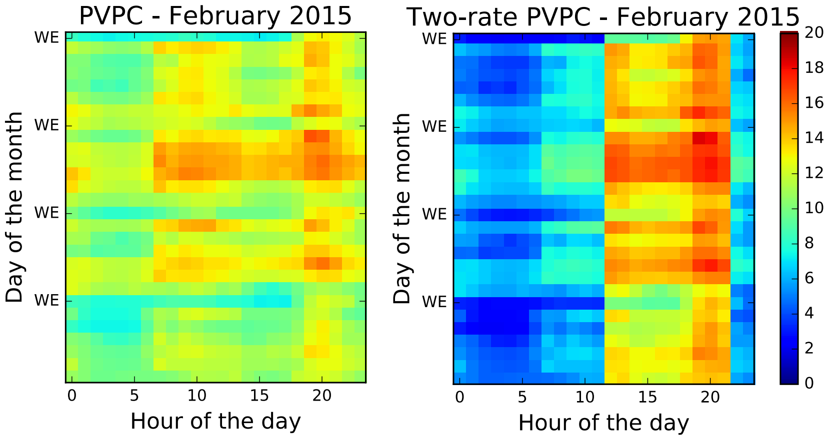
Hourly Prices (regulated tariff)



Data from *Red Eléctrica Española*

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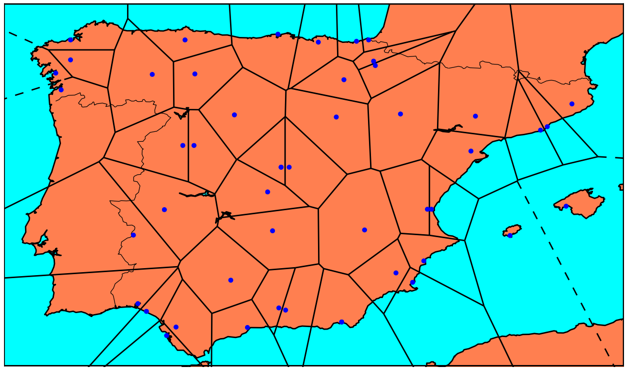
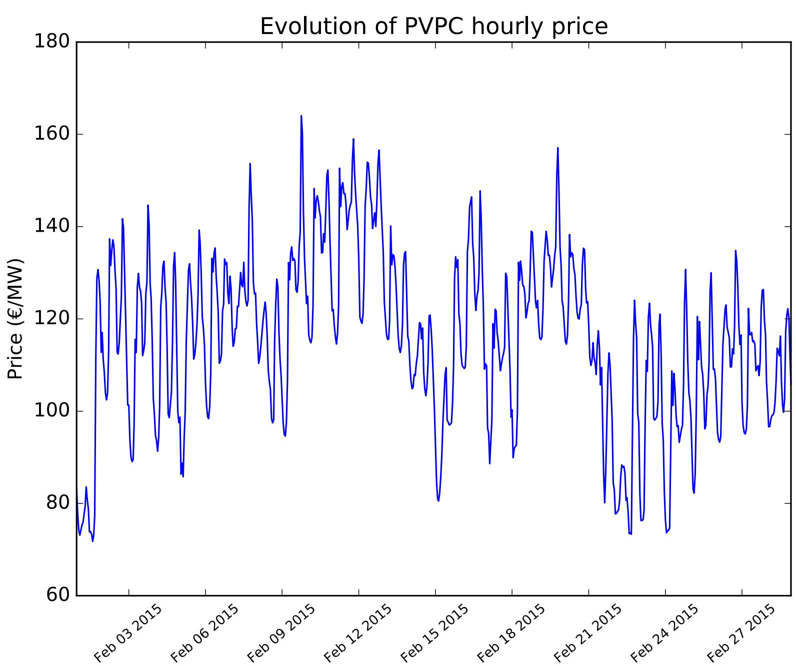
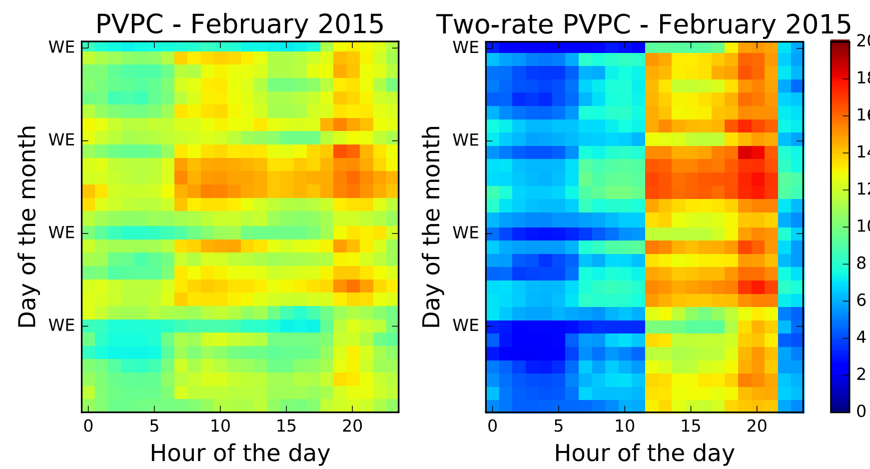


Solar Radiation Data

Data from OpenSolarDB.org

THE PVPC: A FIRST KEY TO INCREASE THE EFFICIENCY

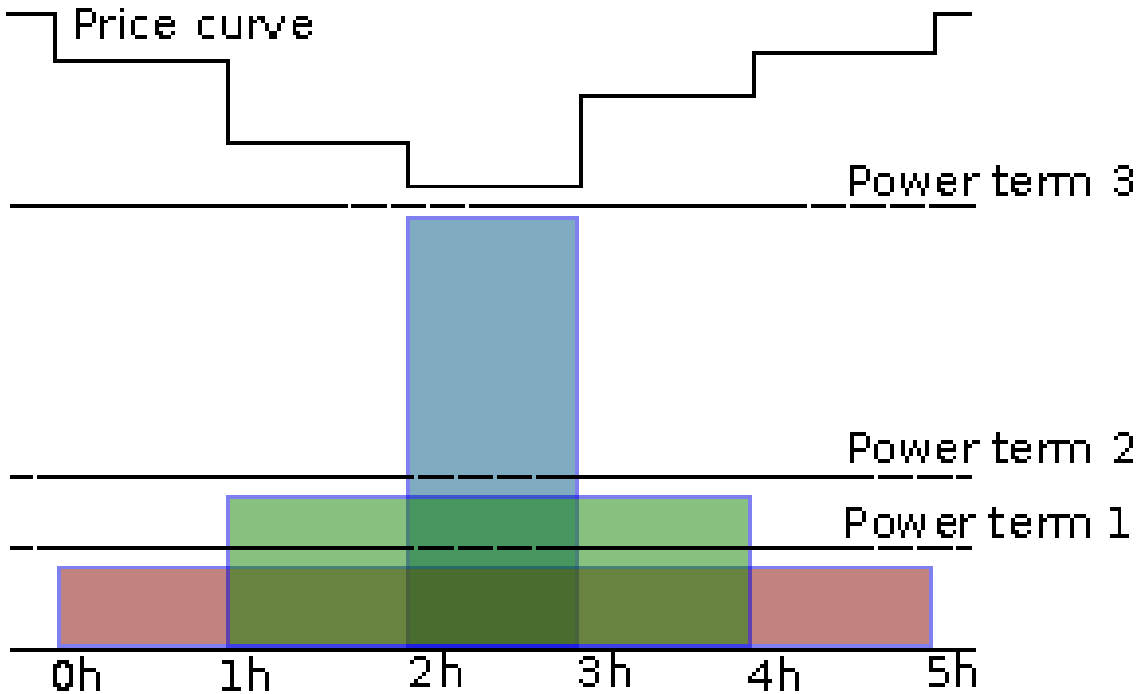




Data from *Red Eléctrica Española*

FIRST (SIMPLER) APPROACH: USE DOMESTIC ENERGY STORAGE

- Key idea: per-customer optimization of the overall cost (power-term + energy term) using batteries.
- We aim at obtaining the energy at cheap hours and spend them at the expensive ones.



FIRST (SIMPLER) APPROACH: USE DOMESTIC ENERGY STORAGE

Elements:

- e_d^n is the energy consumed at day *d*, hour *n*, and $E_d = \Sigma_n e_d^n$
- *P* is the contracted power term.
- c_d^n is the price of the kWh from the grid at day *d*, hour *n* (assumed sorted)
- c_P is the price of each kW in the power term
- γ is the round-trip factor of the battery
- h_d is the number of hours it takes to charge the battery at a speed not exceeding *P* at day *d*

We perform a grid-search over the available values of *P* that minimizes:

$$\sum_d \Big[\underbrace{\sum_{n=1}^{h_d - 1} P c_d^n + (\gamma E_d \mod P) c_d^{h_d}}_{\text{Energy-term}} + \underbrace{P c_P}_{\text{Power-term}} \Big]$$

DOMESTIC ENERGY STORAGE

- The total cost (power term + energy term) is re-evaluated for each user after the optimal *P* is obtained.
- What is the saving per kWh that makes the installation profitable?

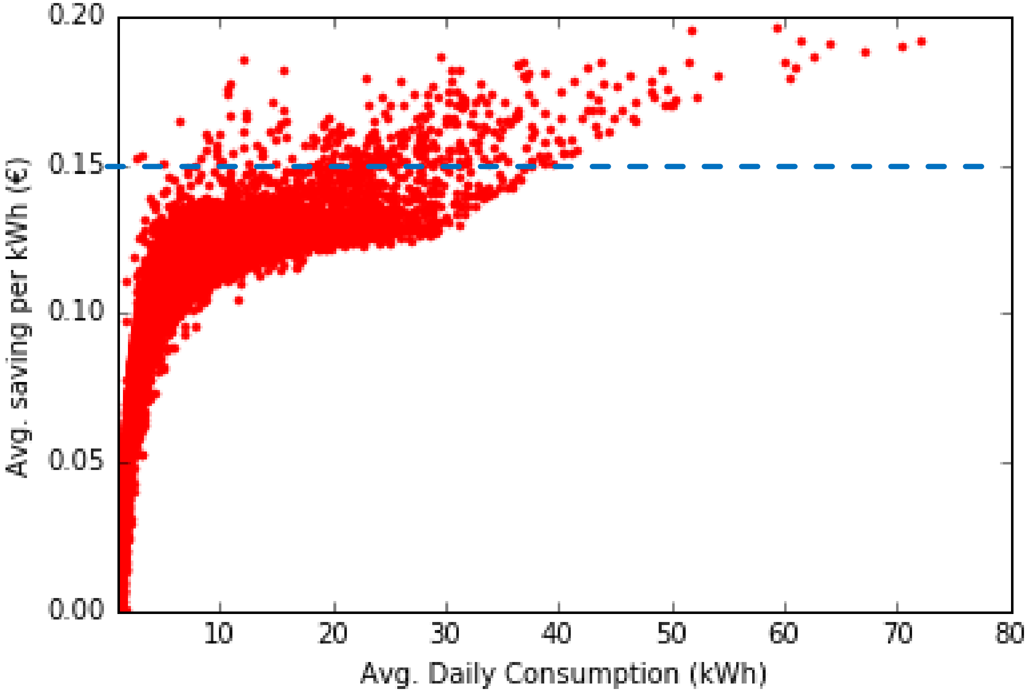
  As a reference, we use the specifications of the Tesla Powerwall, and assume an initial cost of 400€ per kWh, a 80% efficiency (which incorporates the round-trip loss, the inverter and the degradation along the lifetime of the battery) and an operational life of 5000 cycles [1].

- In conclusion, a saving of **15 €/kW**h returns the investment.

[1]Christopher Helman, " Why Tesla's Powerwall Is Just Another Toy For Rich Green People",*Forbes*, May 1st, 2015.

DOMESTIC ENERGY STORAGE

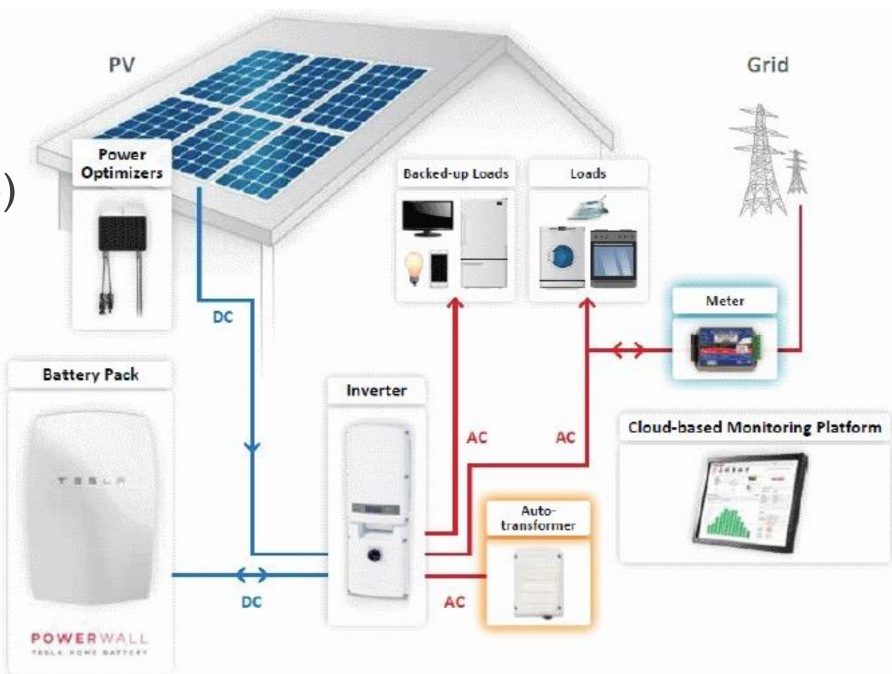
Results



A good amount of users can save more than 15 cts/kWh!

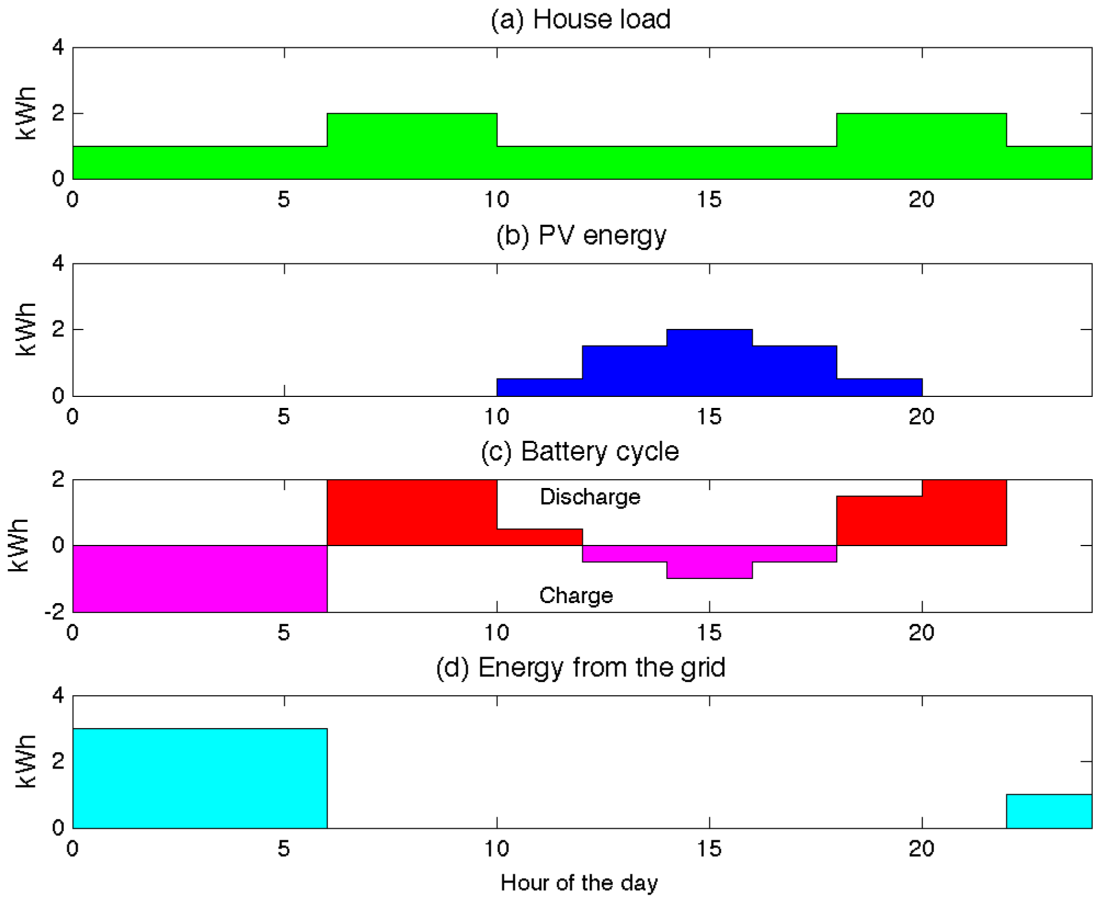
LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

- Now, we consider that we have a PV installation in addition to the batteries.
- In this case there are many degrees of freedom:
  - Each kWh obtained from the PV panels can be 1) spent, 2) used to charge the batteries, or 3) both.
  - Each kWh consumed by the house can be obtained from 1) the grid, 2) the batteries, or 3) directly from the PV panels.
  - The batteries can be charge either 1) from the grid or 2) from the PV panels.



LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

Example: 24 h cycle in a house equipped with both batteries and PV



LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

New elements:

- P_S is the PV power installed.
- B is the storage capacity (battery)
- C_S is the cost of each kW of PV power installed.
- C_B is the cost of storing each kWh of electricity.
- $S_d = \alpha(d)\ P_S$ is the solar energy obtained from the panels along day *d*,
- G_d is the energy stored in the battery along day *d*

With this elements, we can evaluate the *best-case* saving (assume that both the solar and the stored energy can be substracted from the most expensive components of the bill).

This time, we do not optimize *P* since we are allowed to consume directly from the grid.

LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

For each user, we jointly optimize:

1. The PV power installed
2. The storage capacity

$$\underset{P_S, B}{\text{minimize}} \quad \sum_d \Big[\underbrace{P_S C_S \alpha(d)}_{\text{Cost of solar power}} + \underbrace{C_B G_d}_{\text{Cost of batteries}} + \underbrace{\sum_{n=1}^{5} c_d^n \frac{G_d}{5}}_{\text{Cost of energy to store}} + \underbrace{\min_{\mathbf{r}} \sum_{n=1}^{24} r_d^n c_d^n}_{\text{Cost of non-stored energy}} \Big]$$

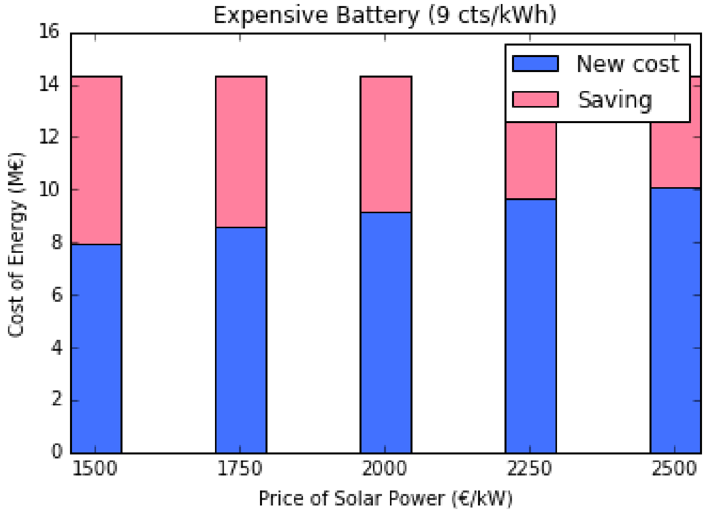
$$\text{subject to} \quad G_d = \min\{B, \gamma E_d - S_d\}$$

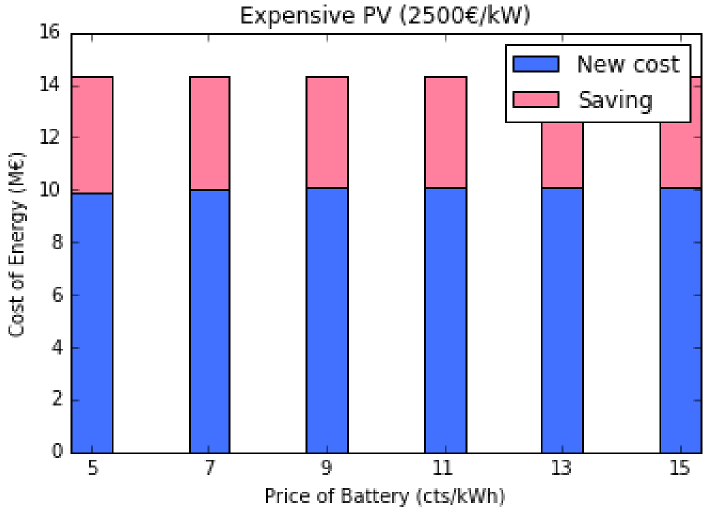
$$R_d = \min\{0, E_d - S_d - G_d\}$$

$$R_d = \sum_{n=1}^{24} r_d^n$$

LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

Results: Overall savings of the 44.000 users during an average period of 330 days

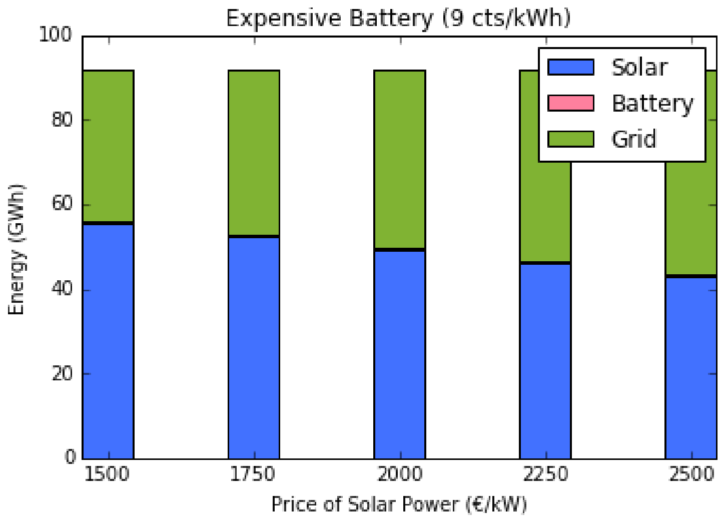


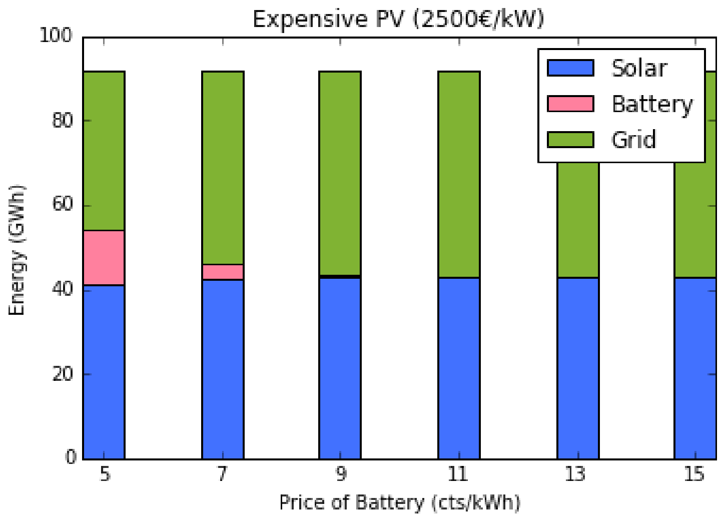


Saving are in the range 4-6 M€! (**100-150 € per user and year**)

LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

Results: Structure of the Domestic Pool





- The role of the batteries is marginal unless they are really cheap.
- **The optimal choice is always to keep connected to the grid!**

LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

A more realistic scenario considers the vector of hourly values of solar radiation.

- ***r*** is the vector of 24 hourly values of energy obtained from the grid.
- ***b*** is the vector of energy values charged to or discharged from the battery.
- ***e*** is the vector with the hourly load of the house.
- ***s*** is the vector of energy values obtained from the PV.
- P_C and P_B are the maximum charge and discharge speeds

Then, $\mathbf{e} + \mathbf{b} = \mathbf{r} + \mathbf{s}$

LEVERAGE OF THE EFFICIENCY WITH SOLAR PANELS

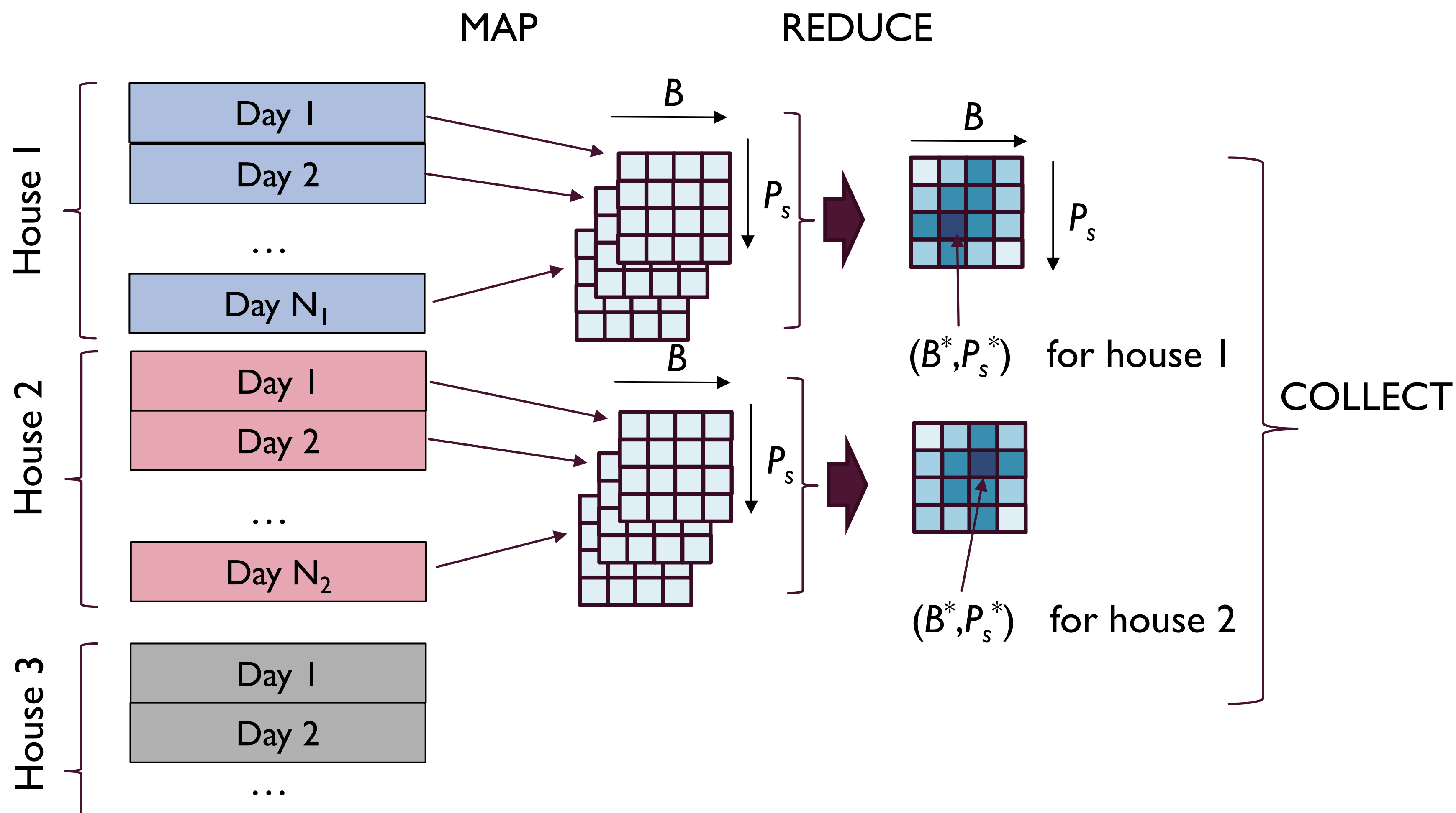
- A more realistic scenario considers the vector of hourly values of solar radiation.
- For each P_S and B, we solve the optimization problem:

$$
\begin{aligned}
\underset{\mathbf{r}}{\text{minimize}} \quad & \mathbf{c}^T \mathbf{r} \\
\text{subject to:} \quad & \mathbf{b} = \mathbf{r} - \mathbf{e} + \mathbf{s} \\
& g_n \geq 0 \\
& \sum_{n=1}^{N} b_n \leq B, \quad N = 1, \ldots, 23 \\
& \sum_{n=1}^{N} b_n \geq 0, \quad N = 1, \ldots, 23 \\
& \sum_{n=1}^{24} b_n = 0 \\
& -P_B \leq b_n \leq P_C
\end{aligned}
$$

IMPLEMENTATION IN SPARK

- The cost of the 32 million daily data is computed in parallel (*map()* method)
  - In a grid of values of P
  - In a grid of values of (P_S, B).
- Then, the grid of results for each user is compiled by a *reduceByKey()* method.
- Results are collected by a *collectAsMap()* method.
- The optimal value of P^* or (P_S^*, B^*) is then obtained for each user.

IMPLEMENTATION IN SPARK



CONCLUSIONS

- It is possible to evaluate the impact of adopting alternative energy technologies (batteries + PV panels).
- The utility companies (retail electricity companies) have plenty of data to design appropriate products.
- Accurate solar radiation data are necessary for a better estimation.
- The *utopia* of disconnecting from the grid is not advised by the numbers: <u>it is better to keep connected</u> and obtain cheap *kWhs* from it.

THANKS!