

# Modelli di produzione fotovoltaica e di domanda elettrica residenziale e industriale

Giulio Presti

Relatore

Prof. Giuseppe De Nicolao

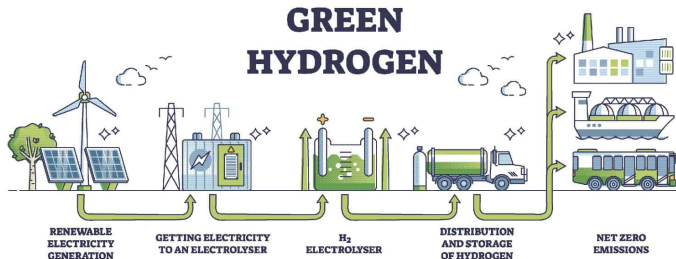


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Università di Pavia

30/04/2025

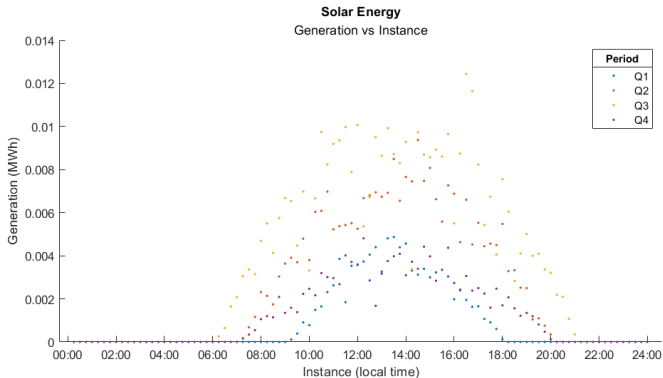
## AIMMS-MOPTA 2024 Competition

- Modeling and Optimization: Theory and Applications Conference
- Lehigh University (USA)
- “Would a Fully Renewable Energy Grid benefit from adding Green Hydrogen as a Supplemental Power Source?”



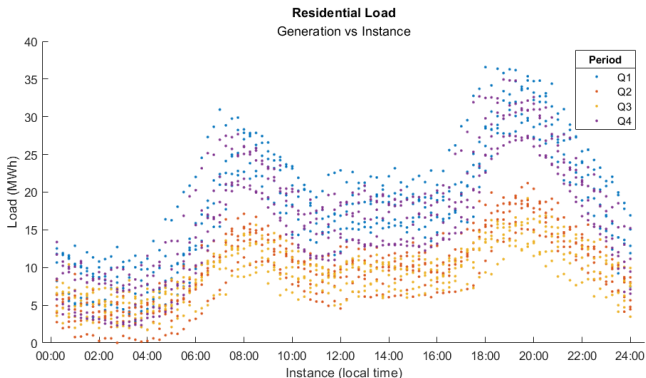
# Dataset (II) - Produzione fotovoltaica

- Totale campioni: 384 (Generation)
  - Quarter: 4 giornate
  - Instance: 96 rilevamenti (15 m)



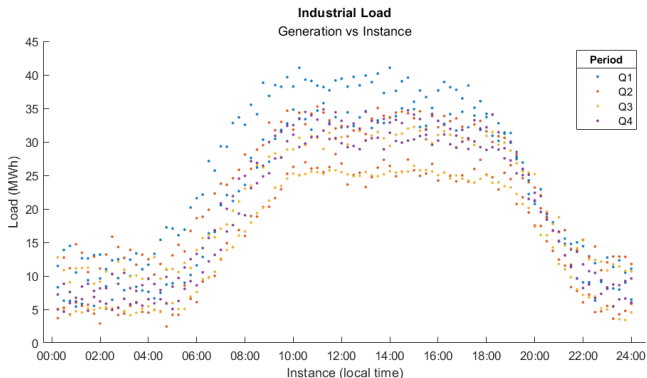
# Dataset (III) - Consumi elettrici

- Totale campioni: 2688 (Load)
  - Quarter: 4 giornate
  - Location: 7 posizioni
  - Instance: 96 rilevamenti (15 m)



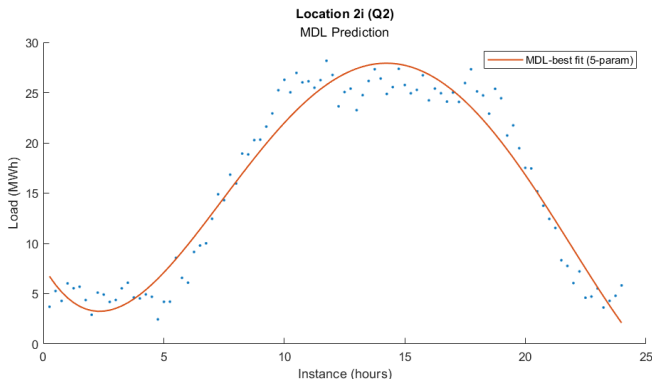
# Dataset (III) - Consumi elettrici

- Totale campioni: 2688 (Load)
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# Consumi elettrici - Modelli polinomiali

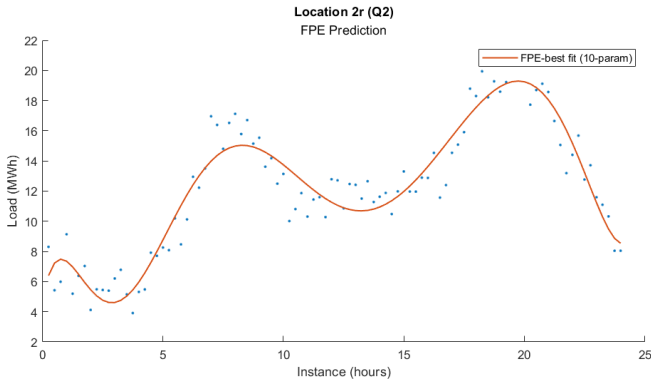
- Minimi quadrati
- $F(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 \dots$
- Scelta modello: *Test F*, *FPE*, *AIC*, *MDL*, *Crossvalidazione*



$$MSE = 5.47 \text{MWh}^2 \text{ e } R^2 = 0.95$$

# Consumi elettrici - Modelli polinomiali

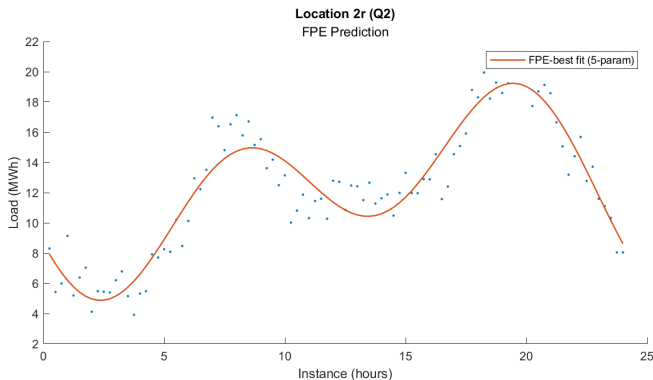
- Minimi quadrati
- $F(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 \dots$
- Scelta modello: *Test F*, *FPE*, *AIC*, *MDL*, *Crossvalidazione*



$$MSE = 1.80 \text{MWh}^2 \text{ e } R^2 = 0.90$$

# Consumi elettrici - Serie di Fourier

- $$F(x) = b_0 + b_1 \sin\left(\frac{2\pi}{T}x\right) + b_2 \cos\left(\frac{2\pi}{T}x\right) + \dots + b_{2k-1} \sin\left(k \frac{2\pi}{T}x\right) + b_{2k} \cos\left(k \frac{2\pi}{T}x\right)$$



$$MSE = 2.01 \text{MWh}^2 \text{ e } R^2 = 0.89$$

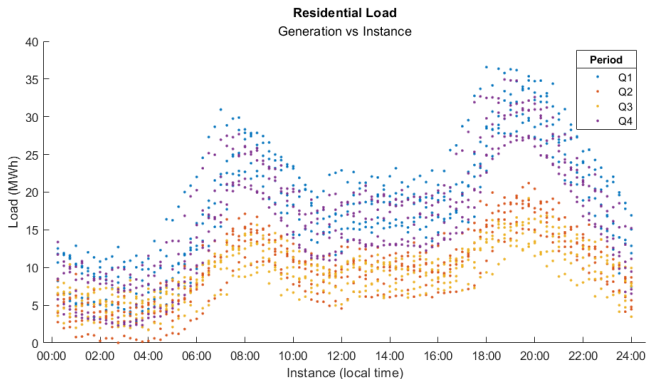


- $$F(x) = b_0 + b_1 \sin\left(\frac{2\pi}{T}x\right) + b_2 \cos\left(\frac{2\pi}{T}x\right) + \dots + b_{2k-1} \sin\left(k \frac{2\pi}{T}x\right) + b_{2k} \cos\left(k \frac{2\pi}{T}x\right)$$
- Confronto performance e flessibilità *polinomi* vs *serie di Fourier*:

Location	Quarter	Model	N-params (FPE)	$R^2$
i1	Q1	Fourier	13	0.9907
i2	Q2	Poli	5	0.9464
r1	Q3	Fourier	5	0.8752
r2	Q2	Poli	10	0.9035

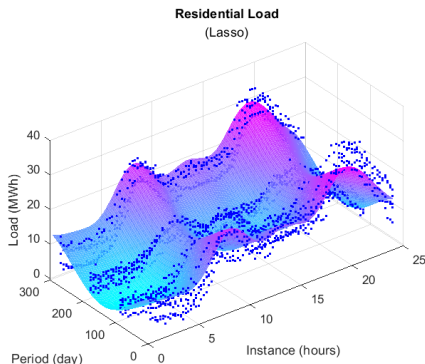
# Consumi elettrici - Modelli additivi 2D

- Modello in *Instance* (hours) e *Quarter* (days)
- $F(h, d) = F_i(h) + c(d)$



# Consumi elettrici - Modelli additivi 2D

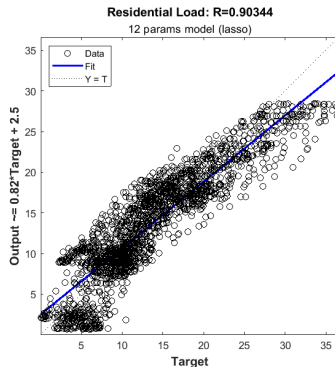
- Modello in *Instance* (hours) e *Quarter* (days)
- $F(h, d) = F_i(h) + c(d)$
- $c(d)$  di tipo polinomiale o periodico



$$MSE = 10.2 \text{MWh}^2 \text{ e } R^2 = 0.81$$

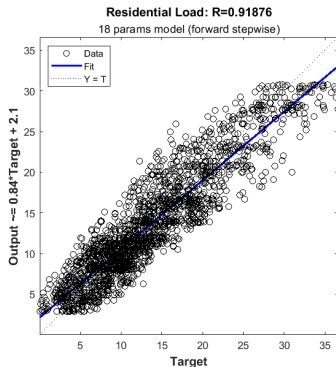
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# Consumi elettrici - Modelli additivi 2D

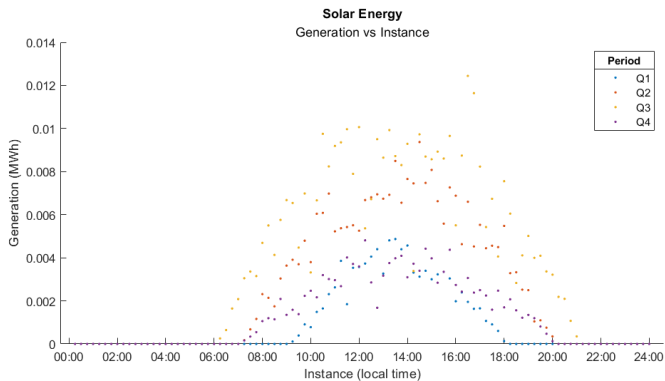
- Modello in *Instance* (hours) e *Quarter* (days)
- $F(h, d) = F_i(h) + c(d)$
- $c(d)$  di tipo polinomiale o periodico



$$MSE = 8.72 \text{MWh}^2 \text{ e } R^2 = 0.84$$

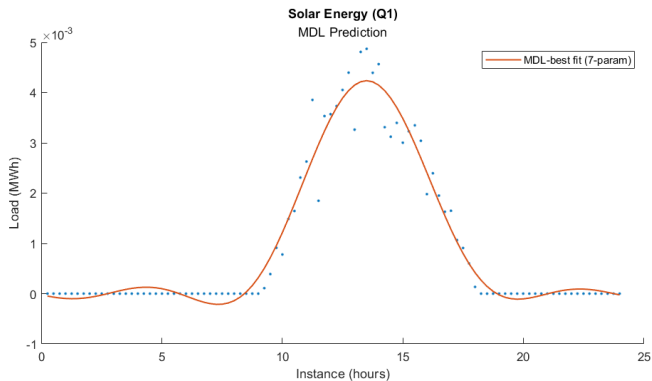
# Generazione solare - Modelli 2D

- Una sola Location



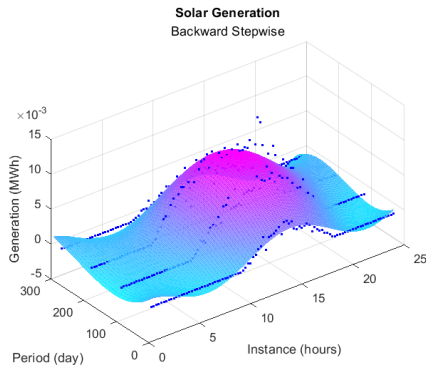
# Generazione solare - Modelli 2D

- Una sola Location
- Problematiche di derivabilità



# Generazione solare - Modelli 2D

- Una sola Location
- Problematiche di derivabilità
- Feature selection: *Lasso*, *Forward stepwise*, *Backward stepwise*

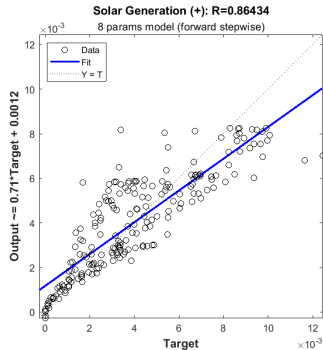


15 parametri,  $MSE = 9.43 \cdot 10^{-7} \text{ MWh}^2$  e  $R^2 = 0.89$



# Generazione solare - Generazione positiva

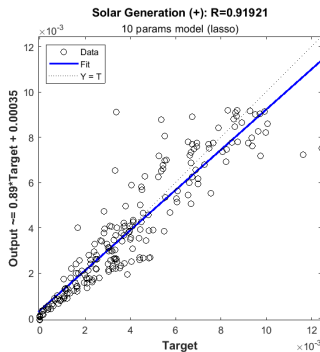
- $\{G|G(h, d) > 0\}$
- Teorema di Gauss-Markov
  - $\theta^{blue} = (\Phi^T \Psi^{-1} \Phi)^{-1} \Phi^T \Psi^{-1} Y$
- $f_l(g) = k \cdot f_l(g|s) \cdot f_l(s)$



$$MSE = 2.05 \cdot 10^{-6} \text{ MWh}^2 \text{ e } R^2 = 0.75$$

# Generazione solare - Generazione positiva

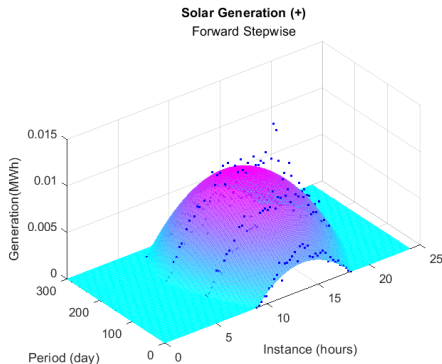
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- $f_I(g) = k \cdot f_I(g|s) \cdot f_I(s)$



$$MSE = 1.29 \cdot 10^{-6} \text{MWh}^2 \text{ e } R^2 = 0.84$$

# Generazione solare - Generazione positiva

- $\{G|G(h,d) > 0\}$
- Teorema di Gauss-Markov
  - $\theta^{blue} = (\Phi^T \Psi^{-1} \Phi)^{-1} \Phi^T \Psi^{-1} Y$
- $f_I(g) = k \cdot f_I(g|s) \cdot f_I(s)$



8 parametri,  $MSE = 2.05 \cdot 10^{-6} \text{MWh}^2$  e  $R^2 = 0.75$

Grazie per l'attenzione

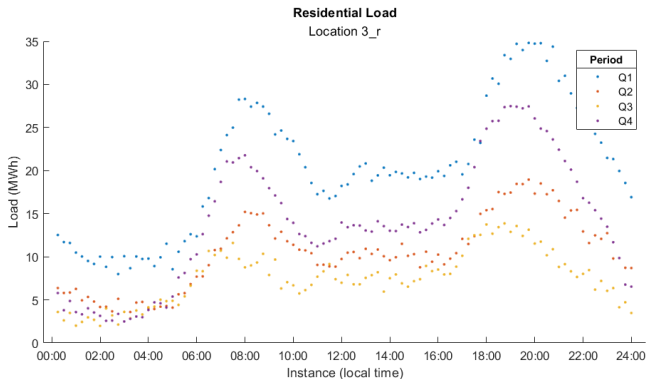
## Esempio matrice di sensitività $\Phi$

```
1 Ty = 365;
2 Td=24;
3
4 Phi=@(instances , periods)[
5     instances.^0 ... % cost
6     ... % 1 ord
7     cos(1*2*pi/Td*instances) sin(1*2*pi/Td*instances)...
8     cos(1*2*pi/Ty*periods) sin(1*2*pi/Ty*periods)...
9     cos(1*2*pi/Td*instances).*cos(1*2*pi/Ty*periods) sin
10    (1*2*pi/Td*instances).*cos(1*2*pi/Ty*periods)...
11    cos(1*2*pi/Td*instances).*sin(1*2*pi/Ty*periods) sin
12    (1*2*pi/Td*instances).*sin(1*2*pi/Ty*periods)...
13    ... % 2 ord
14    cos(2*2*pi/Td*instances) sin(2*2*pi/Td*instances)...
15    cos(2*2*pi/Ty*periods) sin(2*2*pi/Ty*periods)...
16    ... % altri ordini
17 ]
```

- MOPTA24 Competition Dataset,  
<https://coral.ise.lehigh.edu/~mopta2024/>.
- MOPTA24 Competition Dataset, *MOPTA Competition Optimization Problem*, Marco Capelletti, Luca Danna, Anna Sacilotto.
- *The Elements of Statistical Learning*, Trevor Hastie, Robert Tibshirani, Jerome Friedman.

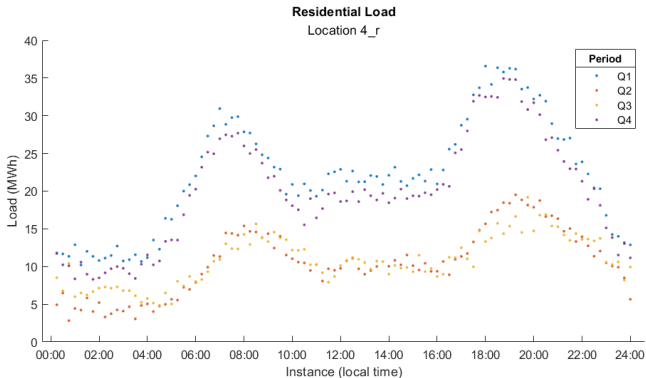
# Load Quarter - Problemi

- “This demand data can be considered indicative of a typical demand pattern for the region during that quarter.” (AIMMS-MOPTA 2024 - "Data")
- Il testo della competizione non specifica la regolarità del campionamento durante l'anno.



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# Blackout - Spagna

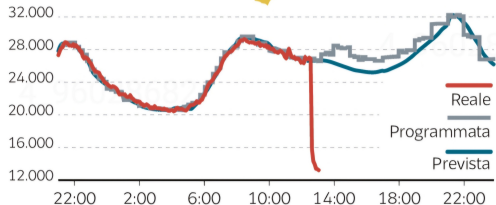
- Poco prima che si verificasse il blackout, si è avuto un picco di produzione di energia solare.
- Lunedì 28 alle 12.30

## La domanda

La richiesta di energia elettrica e l'area interessata dal blackout



Domanda (MWh)



Fonte: rete elettrica spagnola

Corriere della Sera