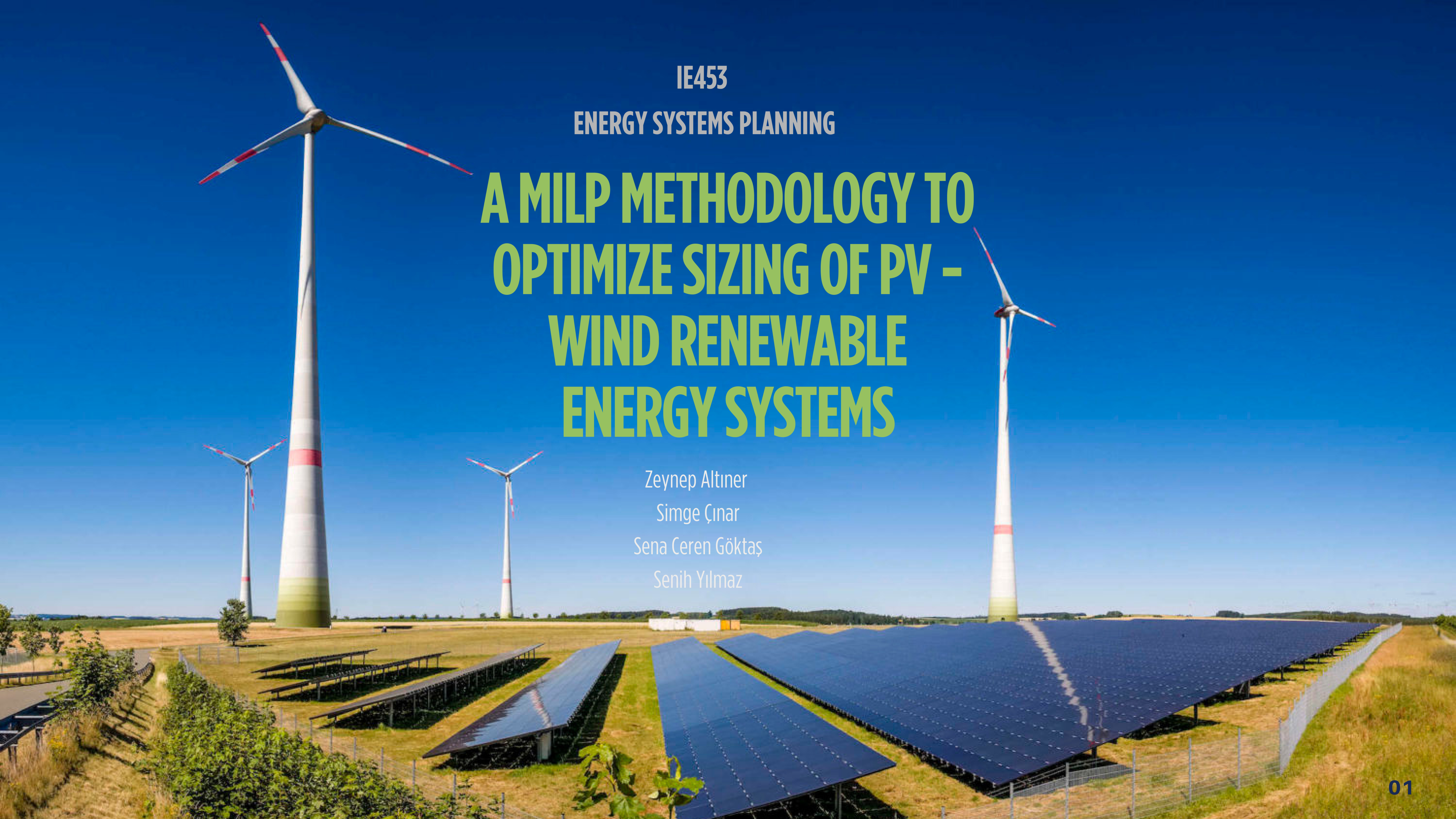


IE453

ENERGY SYSTEMS PLANNING

# A MILP METHODOLOGY TO OPTIMIZE SIZING OF PV – WIND RENEWABLE ENERGY SYSTEMS

Zeynep Altıner
Simge Çınar
Sena Ceren Göktaş
Senih Yılmaz

# CONTENTS OF THE PRESENTATION

# SUMMARY OF THE PAPER


The Italian policy has encouraged the growth of RESs in order to support the use of clean energy in the European green economy context. [1]


Developing a MILP model to calculate the optimal sizing of a hybrid wind-photovoltaic power plant in an industrial area to support this policy. [1]


# SUMMARY OF THE PAPER

The proposed approach aims to jointly determine both optimal sizes of the renewable plants and the amount of network energy from the grid that satisfies load requirements by minimizing the sum of the daily cost of the energy purchased and the daily operatingand maintenance costs of RESs [1].

## SIZING OF WIND TURBINES AND PV PANELS

A MILP model to determine the optimal size of the wind and PV apparatuses of a power plant is proposed

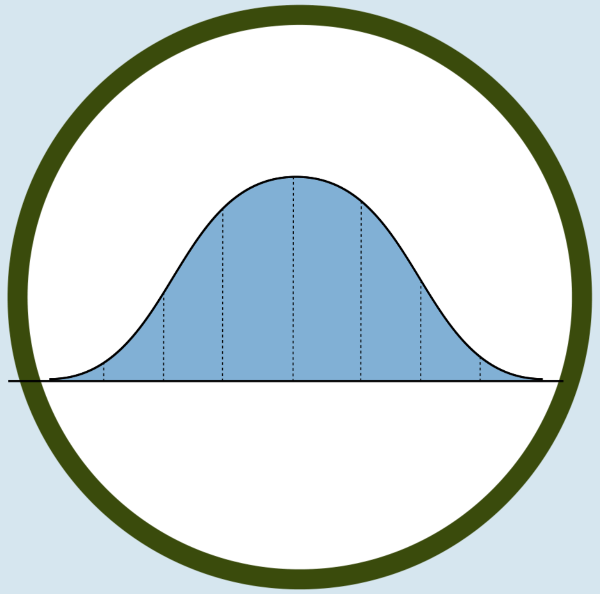
## FINANCIAL ANALYSIS

An integrated economic analysis of the investment through the net present value (NPV) method is also performed, which allows the convenience of the proposed system to be evaluated over its lifetime.

# MODIFICATIONS AND ASSUMPTIONS

### WEATHER CONDITIONS

Mean of the weather conditions are assumed to be equal over different years

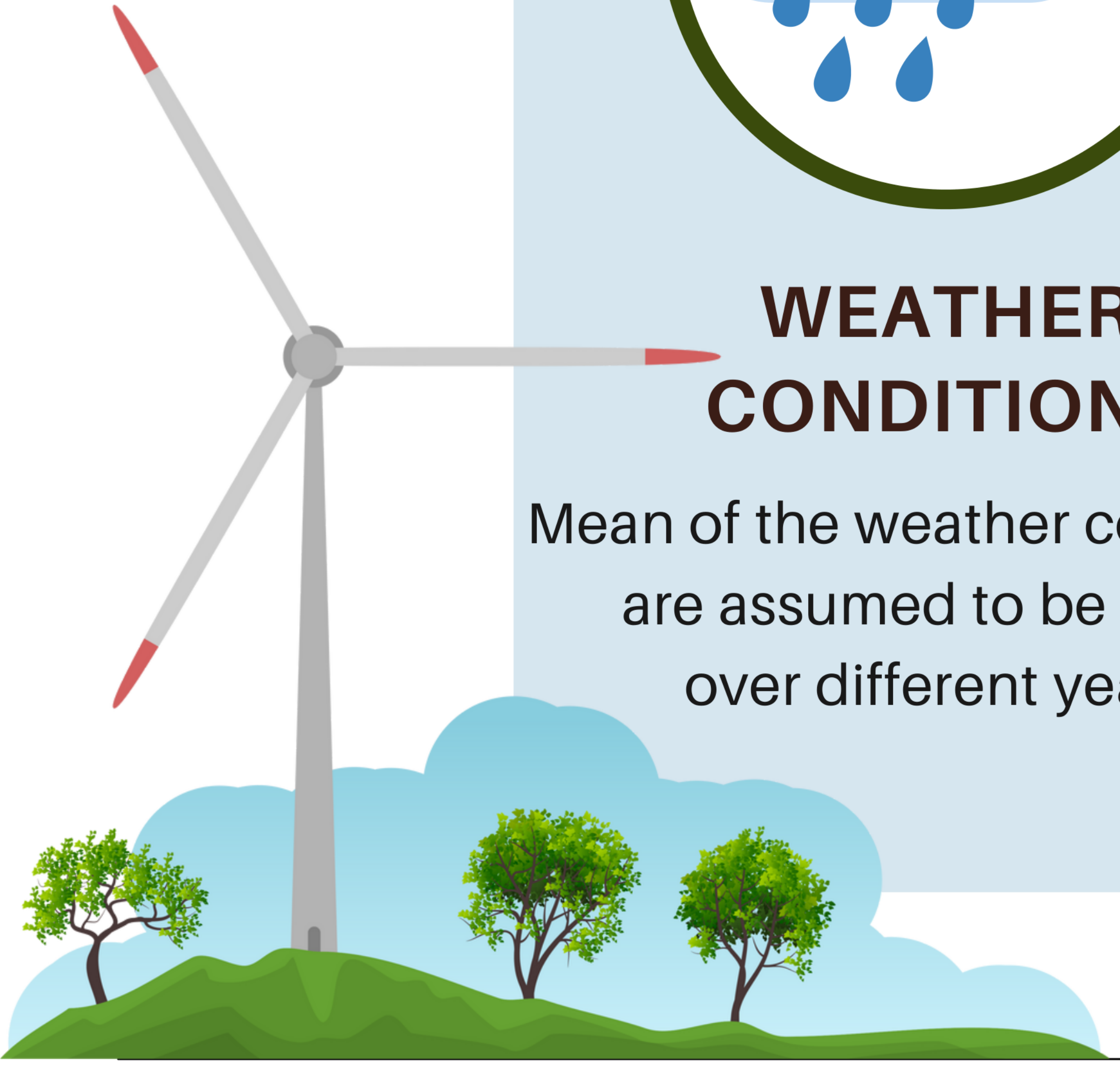


### RANDOMNESS

Data contains random generated noise to imitate the unexpected variations for individual points

### CURTAILMENT

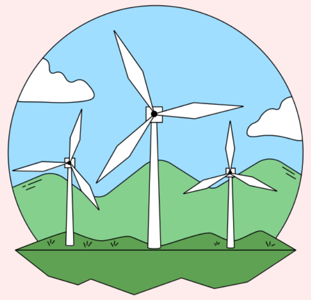
Amount of curtailment for both systems added to the system



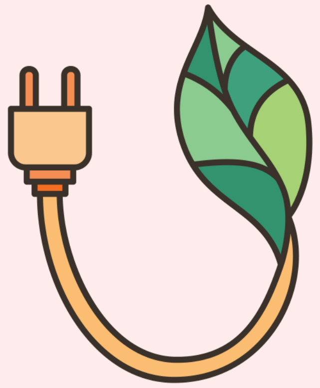
# MIXED-INTEGER LINEAR PROGRAMMING MODEL

## Classification of Parameters

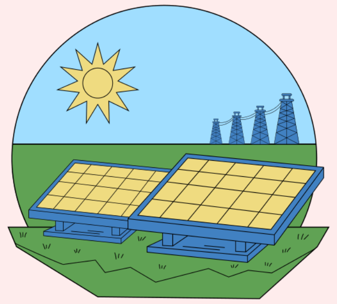
### DEMAND/ENERGY



**WIND POWER IN EACH INTERVAL**

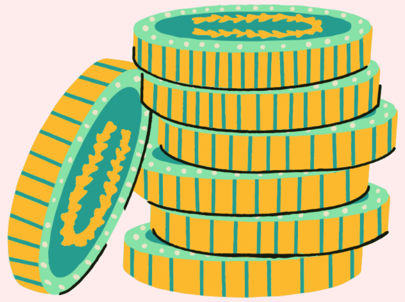


**LOAD POWER DEMAND IN EACH INTERVAL**

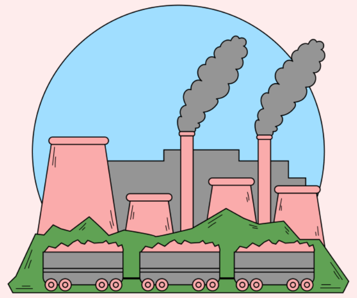


**SOLAR RADIATION IN EACH INTERVAL**

### COSTS



**AVAILABLE BUDGET**

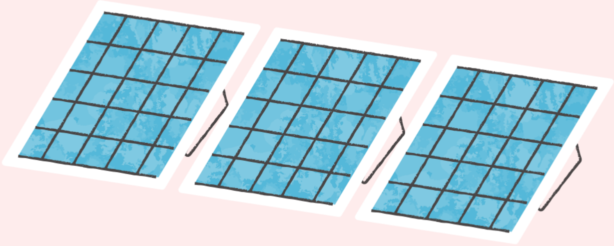


**OPERATION AND MAINTANENCE COSTS**

**INSTALLATION COSTS**

### GEOMETRIC

**AVAILABLE AREA FOR WIND TURBINES AND SOLAR PANELS**



**DIMENSIONAL SPECIFICATIONS FOR PV**

# MIXED-INTEGER LINEAR PROGRAMMING MODEL

## Parameters

$C_w \rightarrow$ Unit O&M cost of wind turbines, (€/kW)

$C_{pv} \rightarrow$ Unit O&M cost of PV panels, (€/kW)

$C_{network} \rightarrow$ Unit cost of purchased energy, (€/kWh)

$P_W \rightarrow$ Wind turbine power production in the $i^{th}$ interval, in kW

$P_{PV} \rightarrow$ PV power production in the $i^{th}$ interval, in kW

$P_{load} \rightarrow$ Load power demand in the $i^{th}$ interval, in kW

$m \rightarrow$ number of minutes in a day

$B \rightarrow$ Fixed budget

$A_b \rightarrow$ Basic ground area occupied by a wind turbine, in $m^2$

$A_{max} \rightarrow$ Available area for wind power plant, in $m^2$

$S_l \rightarrow$ Larger side of available area for PV installation, in m

$L \rightarrow$ Longitudinal dimension of each panel, in m

$s_l \rightarrow$ Smaller side of available area for PV installation, in m

$C_{Winst} \rightarrow$ Unit installation cost of wind turbines, in €

$P_{Pinst} \rightarrow$ Unit installation cost of PV panels, in €

$\beta \rightarrow$ Tilt angle of solar panels

$\gamma \rightarrow$ Height of the sun in winter solstice

## Decision Variables

$W \rightarrow$ Number of wind turbines

$P \rightarrow$ Number of PV panels

$X_i \rightarrow$ Energy purchased from the network at each interval, i $\in T$

$P_{pvd} \rightarrow$ Amount of energy sent from PV to demand point at interval, i $\in T$

$P_{pvc} \rightarrow$ Amount of energy curtailed from PV at interval, i $\in T$

$W_{wc} \rightarrow$ Amount of energy curtailed from wind turbines at interval, i $\in T$

$W_{wd} \rightarrow$ Amount of energy sent from wind turbines to demand point at interval, i $\in T$

# MIXED-INTEGER LINEAR PROGRAMMING MODEL


$$\min \quad 5 \cdot C_w \cdot W + C_{pv} \cdot P \cdot 0.22 + \sum_{i \in T} C_{network} \cdot X_i$$

s.t.

$$P^i_{pvd} + W^i_{wd} + X_i = P^i_{load} \quad \forall i \in T$$

$$P^i_W \cdot W = P^i_{pvd} + P^i_{pvc} \quad \forall i \in T$$

$$P^i_{PV} \cdot P = W^i_{wd} + W^i_{wc} \quad \forall i \in T$$

Demand and Energy Production Costraints

$$C_{Winst} \cdot W + C_{Pinst} \cdot P \leq B$$

$$W \cdot A_b \leq A_{max}$$

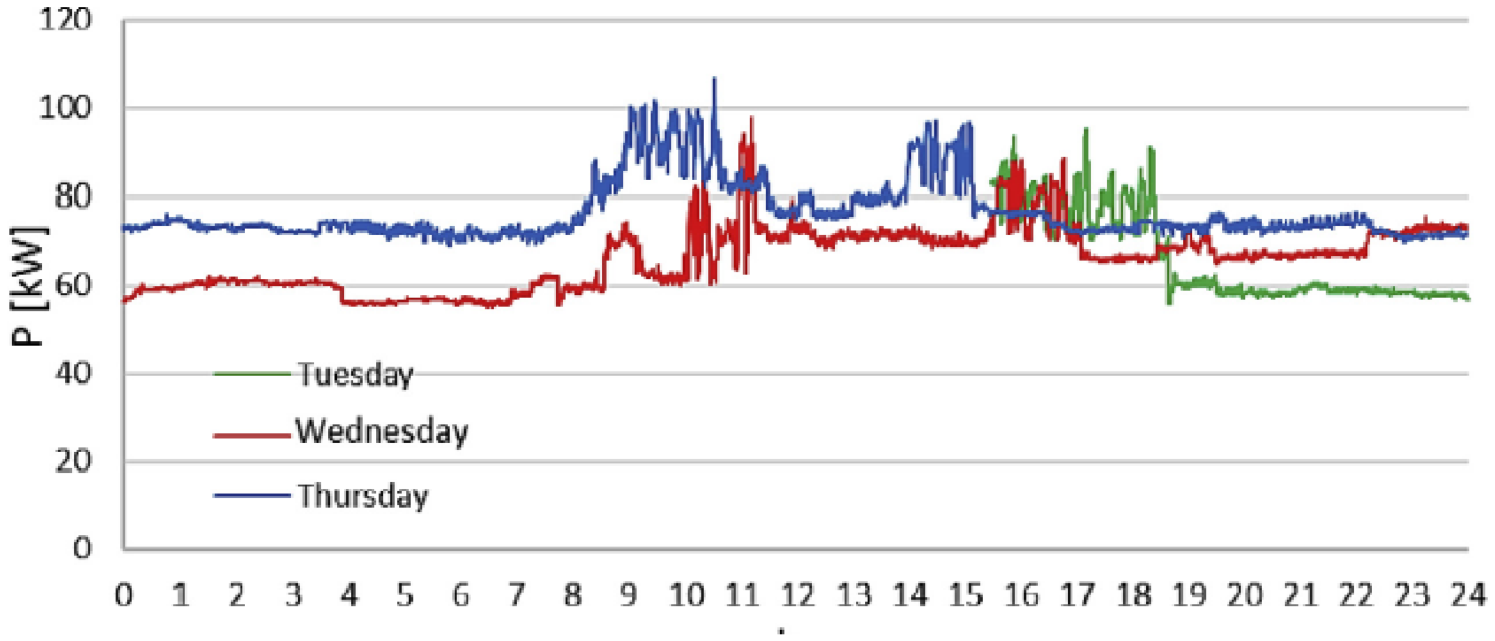
$$P \leq ((S_l - 3) \cdot (s_l - 3))/(L^2 \cdot cos\beta(1 + (\tan\beta / \tan\gamma)))$$

$$\text{all decision var.} \geq 0$$

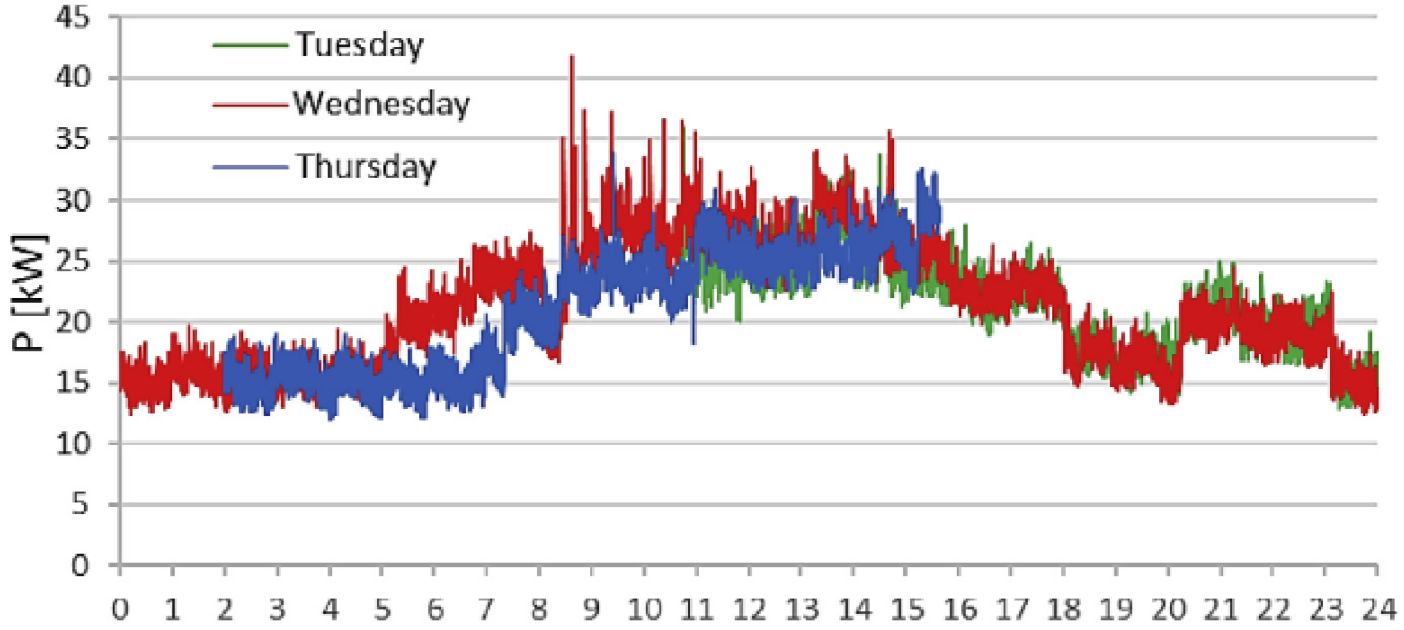
Geometric Constraints

# CASE STUDY: OFFICIANA MAGLIANA

(1) Building maintenance power demand




(2) Refectory, bar, and office power demand



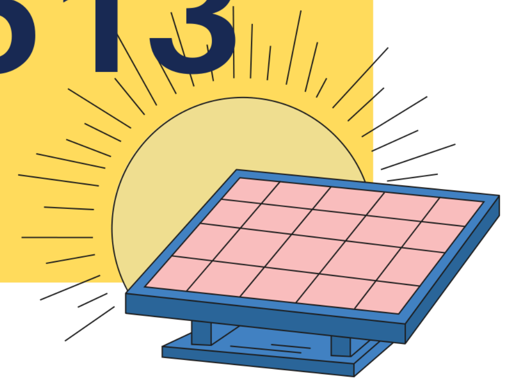

| | |
|---|---|
| 01 Maintenance by external executing company | 06 Control Tower |
| 02 Building maintenance | 07 Roof wagons maintenance |
| 03 Offices, Refectory, Bar, Changing Room | 08 Thermal plant |
| 04 Ecological Island | 09 Electrical component storehouse |
| 05 Warehouse | 10 Blowing and washing |

# MODEL RESULTS

| | # of wind turbine | # of PV panel | Max of purchased energy | Total purchased energy |
|---|---|---|---|---|
| **January** | 3.0 | -0.0 | 61.639886 | 83662.291567 |
| **February** | 3.0 | -0.0 | 55.292611 | 76095.455538 |
| **March** | 3.0 | -0.0 | 40.944466 | 80029.613012 |
| **April** | 3.0 | 413.0 | 70.364568 | 88363.718476 |
| **May** | 3.0 | 426.0 | 83.457703 | 105496.493826 |
| **June** | 3.0 | 385.0 | 66.559307 | 93920.811735 |
| **July** | 3.0 | 395.0 | 73.660213 | 98198.787698 |
| **August** | 3.0 | 486.0 | 85.120983 | 106289.893175 |
| **September** | 3.0 | 513.0 | 81.726217 | 89803.122707 |
| **October** | 3.0 | 409.0 | 57.990020 | 88125.761110 |
| **November** | 3.0 | -0.0 | 74.302000 | 81578.305185 |
| **December** | 3.0 | -0.0 | 85.067525 | 93401.299304 |

3

513



# COMPARISON WITH PAPER

***Case Study***

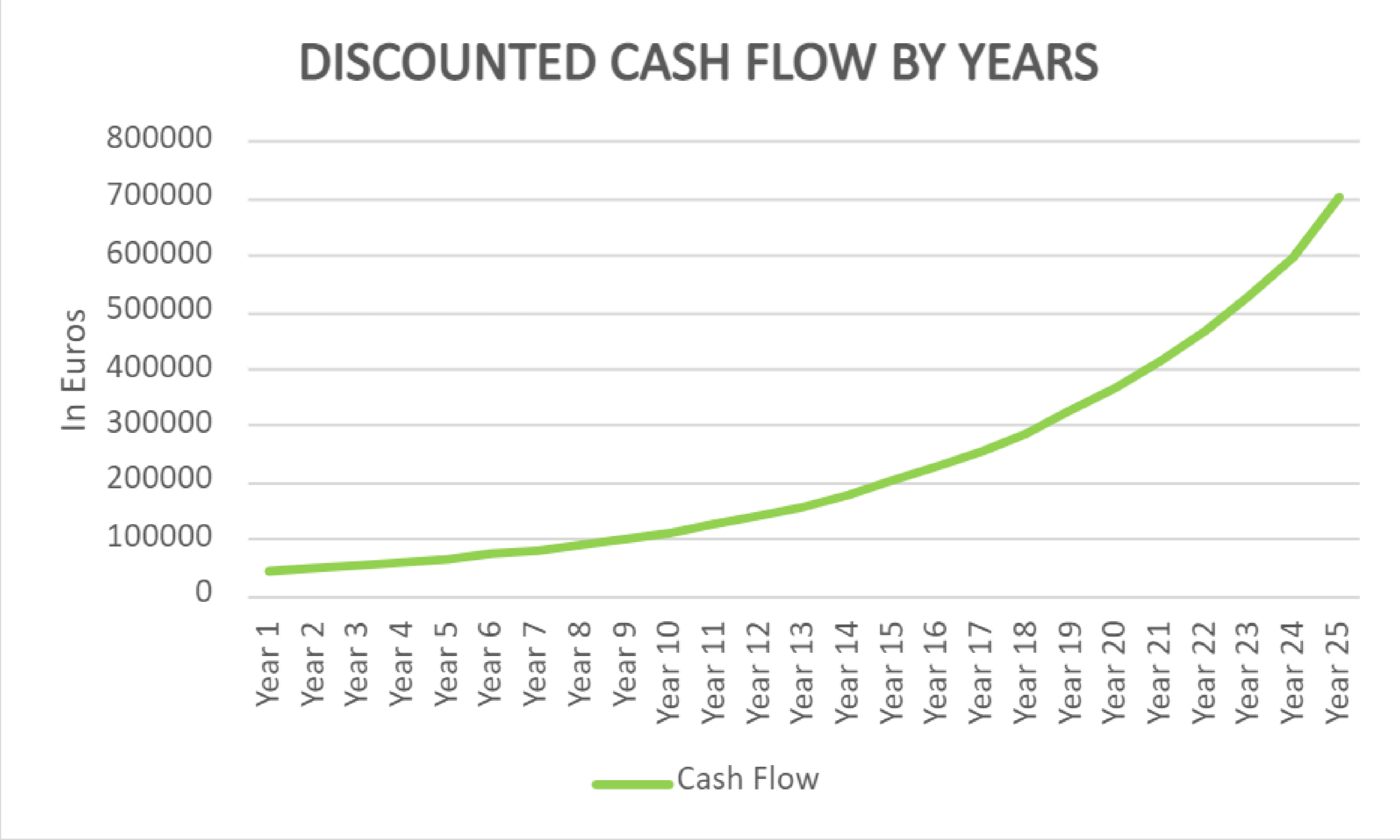
| Month | # of wind turbine | # of PV panel |
|---|---|---|
| January | 3 | 0 |
| May | 3 | 415 |
| July | 3 | 405 |
| October | 3 | 646 |

***Our Implementation***

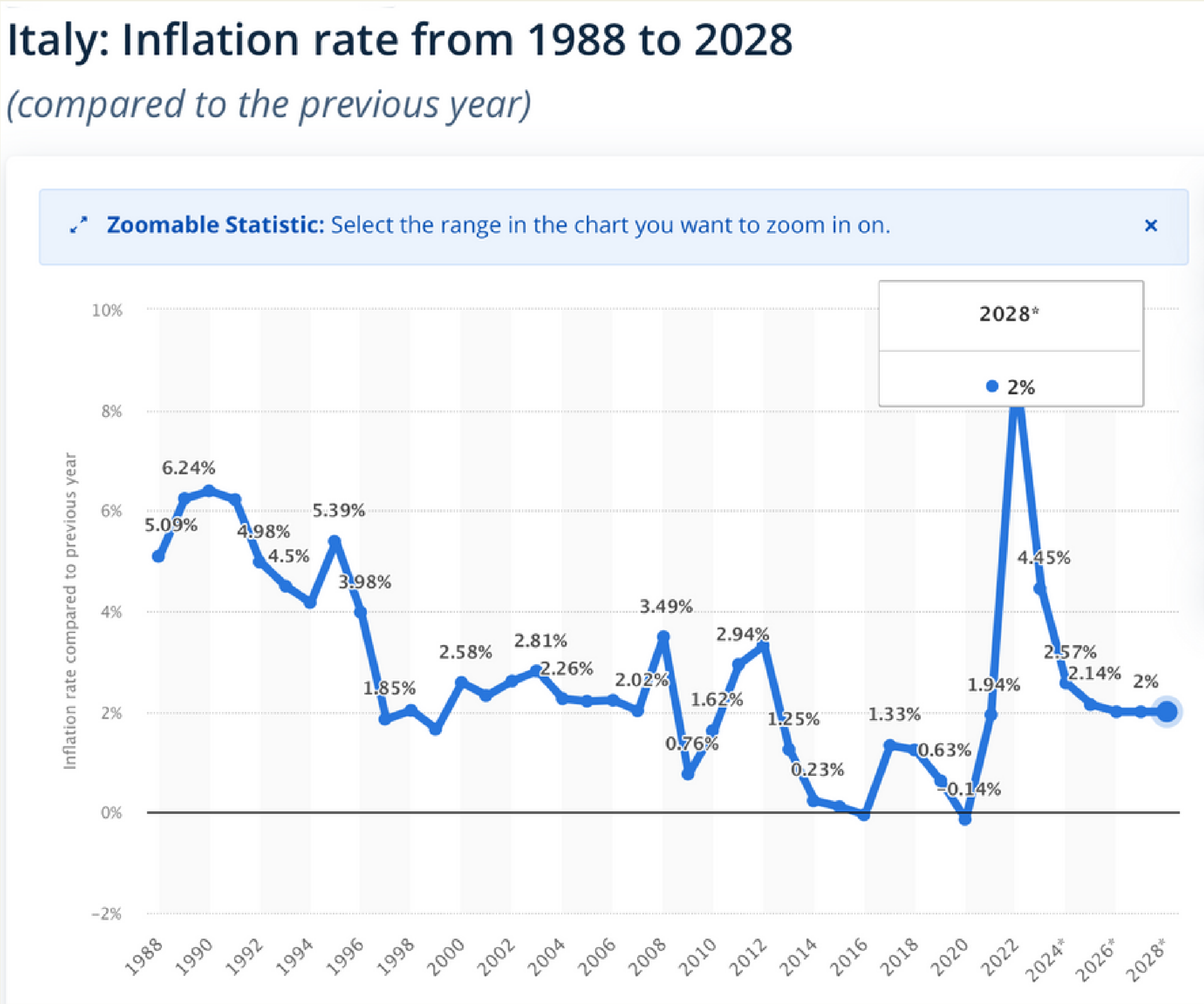
| Month | # of wind turbine | # of PV panel |
|---|---|---|
| January | 3 | 0 |
| May | 3 | 426 |
| July | 3 | 395 |
| October | 3 | 409 |

# FINANCIAL ANALYSIS

| Investment and Maintenance Calculation | |
|---|---|
| (Jan 1st Purchased) with a Budget | € 300,000.00 |
| Number of Solar Panels Purchased | 513 |
| Number of Wind Turbines Purchased | 3 |
| Unit Price of Purchased Solar Panels | 200 |
| Unit Price of Purchased Wind Turbines | 6500 |
| Installation Cost of Solar Panel | 110 |
| Installation Cost of Wind Turbine | 2300 |
| Yearly Maintenance Cost of a Turbine | 41.61 |
| Yearly Maintenance Cost of a Panel | 22.776 |
| (We have used 20% inflation) | |
| We assume installation of PV/Watt | 0.5 |
| Purchasing Price of Battery /kWh | 500 |
| Battery Capacity | |
| | |
| Interest Rate | 3.75 |
| Depreciation Rate | 0.05 |
| Investment | 185430 |
| | |
| Yearly Maintenance | |
| Yearly Purchase of Electricity kWh | |
| Salvage | |
| Net Cash Flow | |
| Discounted Cash Flow | |
| NPV | -5918235.894 |
| | |
| Electricity Prices kWh in Italy | |
| Average Electricity Inflation Rate Per Annum | 1.077242906 |



# CALCULATIONS




Future Inflation Rate Estimation[2]


Future Electricity Price Estimation [3]

# Result of Financial Analysis

## REASON FOR HIGH COST

- Budget constraints to build a higher capacity plant in PV and area constraints in wind turbines

- Inability to store the excess generation to later use or sell it back to the grid

- The amount of energy deficit will remain same; however, the price of electricity will rise faster than the interest rate.
- System does not have any cash inflow such as selling excess

## ACTION FOR COMMITMENT

- Implementing an energy storage system

- Ability to sell the excess to the grid

## Strengths

- The investment analysis gives an intuition about the cost of the system and may attract other investors.
- The model considers geometrical and physical limitations (e.g., shadowing of PVs, allowance of corridors)

## Weaknesses

- Lack of storage devices or demand side management techniques (excess energy curtailed in each interval).
- Energy demand assumed to remain identical in the consecutive years for a facility that will serve decades.
- Highly dependent on market electricity due to intermittency of sources.

# REFERENCES

[1] R. Lamedica, E. Santini, A. Ruvio, L. Palagi, and I. Rossetta, “A MILP methodology to optimize sizing of PV - wind renewable energy systems,” Energy, vol. 165, pp. 385–398, 2018.

[2] O’Neill, A. (2023, April 14). Italy - inflation rate 2028. Statista. https://www.statista.com/statistics/270489/inflation-rate-in-italy/

[3] Italy electricity price2023 data - 2004-2022 historical - 2024 forecast - quote. Italy Electricity Price - 2023 Data - 2004-2022 Historical - 2024 Forecast - Quote. (n.d.). https://tradingeconomics.com/italy/electricity-price

# THANK YOU FOR LISTENING

# QUESTIONS