Blackout risk mitigation by using distributed gas turbine generation: An application to the electrical Spanish distribution network

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1 INTRODUCTION

- The pricing mechanism in the Spanish electrical market
- Actors in the electrical market
- Blackout risk in the distribution network
- Regulation for new investments in the distribution network

THE PROBLEM

- Distributed generation
- Problem statement
- The planning (location and temporal deployment) model

ILLUSTRATION

- The Spanish case

CONCLUSIONS

- Further research

INTRODUCTION. The pricing mechanism in the Spanish electrical market

The electricity price is mainly the consequence of a regulated equilibrium between electricity supply and demand.

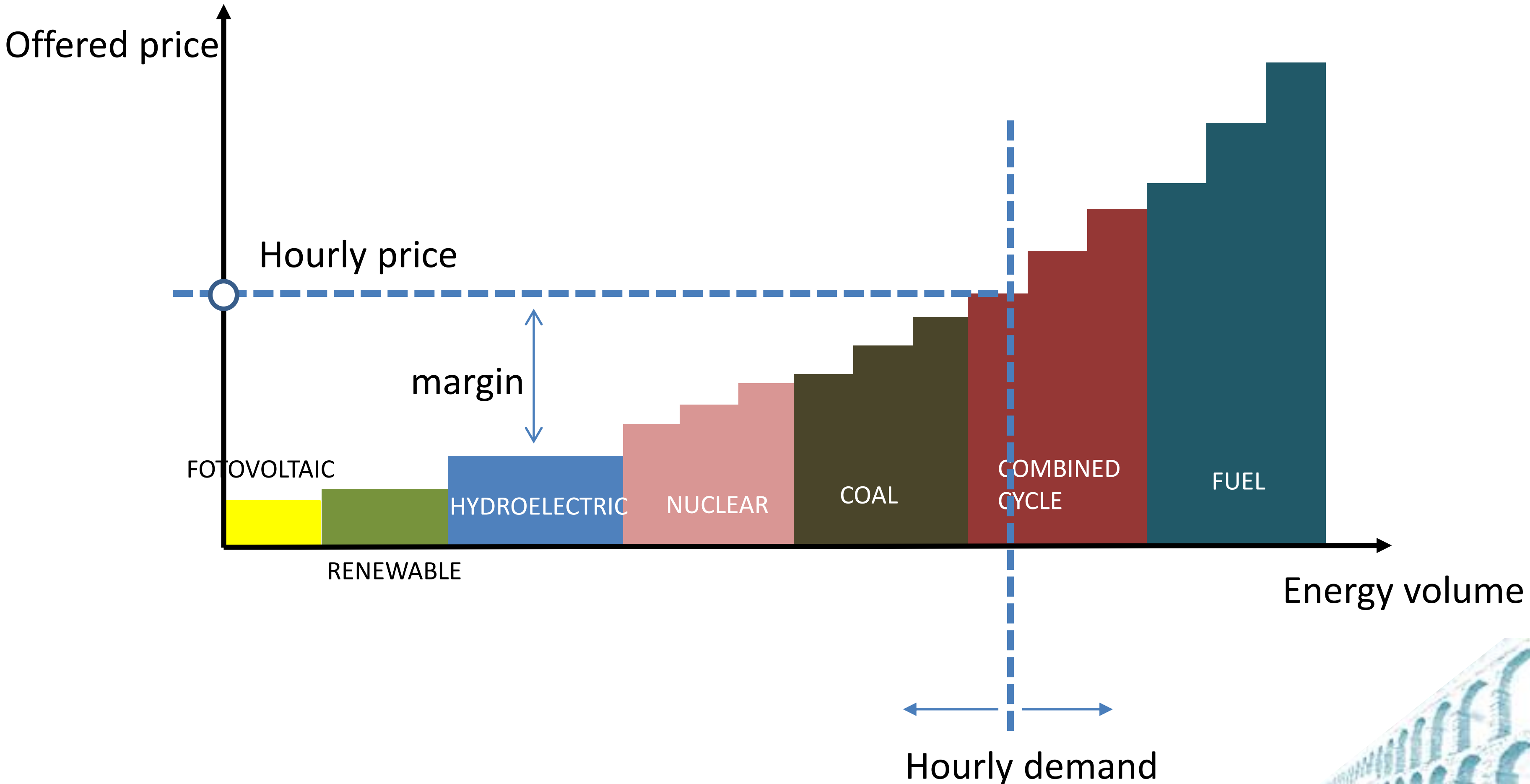
Generation is performed using different technologies, each one with a different marginal cost (€/Mwh). In practice, different generators using the same technology may incur in a different marginal production cost.

For some technologies (for instance those related with the sun energy or the wind) the capacity of production varies along the day and the season.

The electricity price is fixed accordingly to an hourly public auction where, in theory, each generator offers a price which should be greater than its marginal cost* (price > marginal cost) .

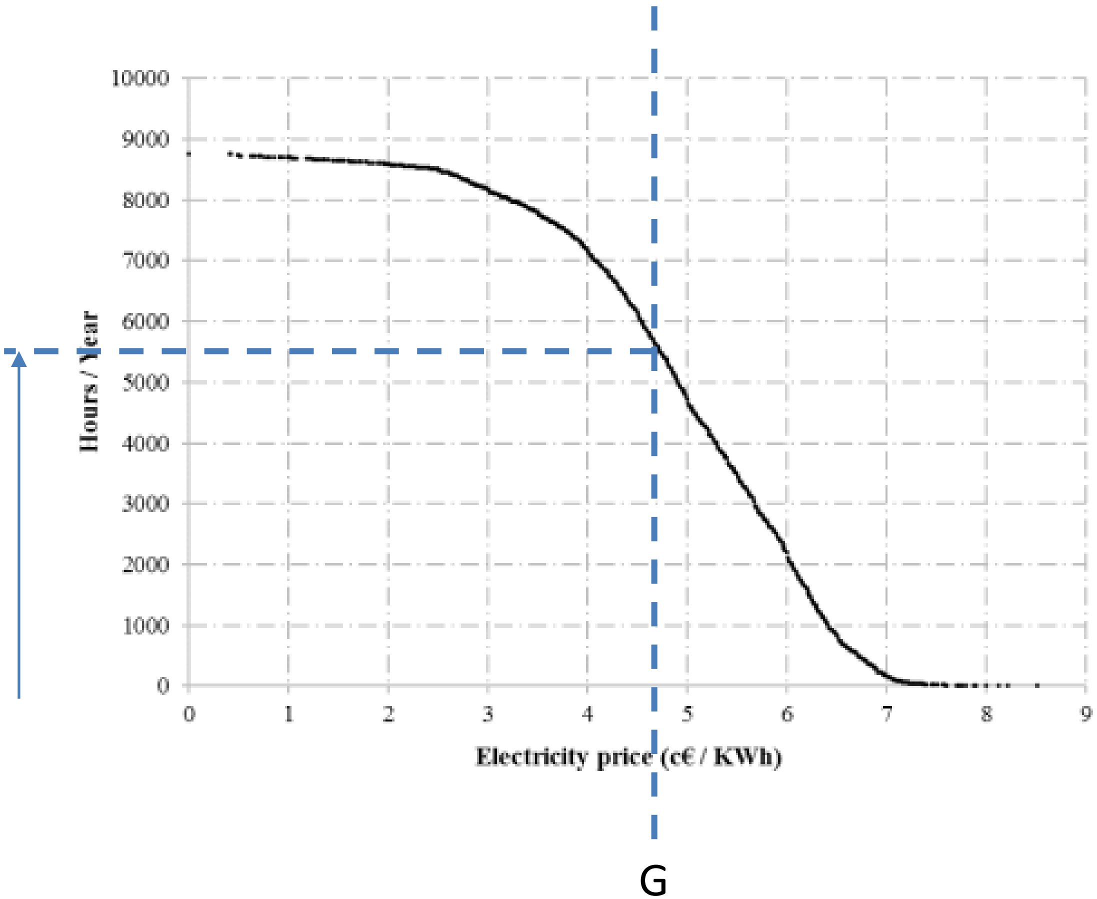
The hourly price is fixed as a function of the demand. As the marginal production cost depends on the technology, the price is fixed to higher marginal cost among the necessary generators (depending on its production capacity) so that the expected demand is fulfilled.

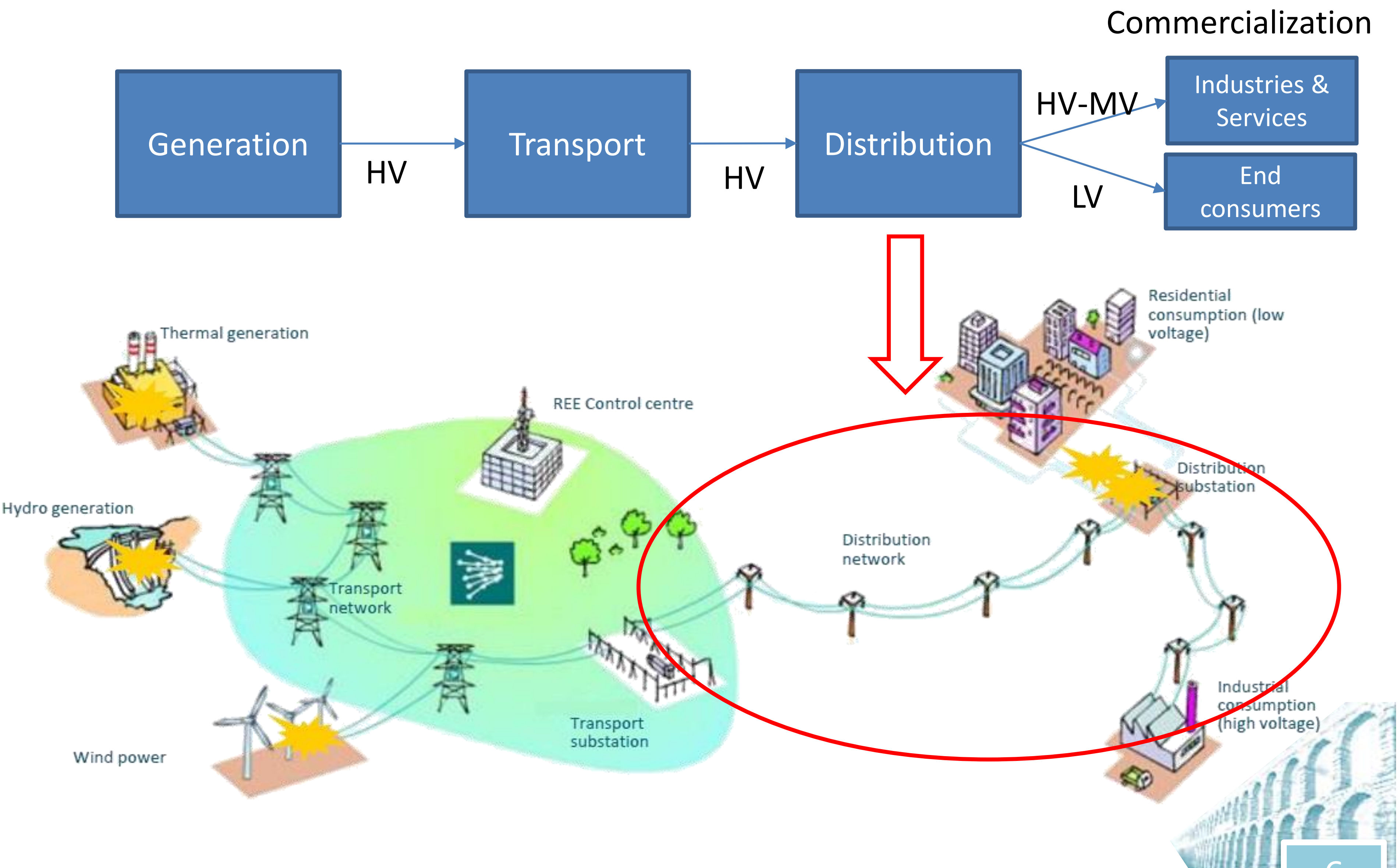
Generation cost depending on generation technology and pricing mechanism



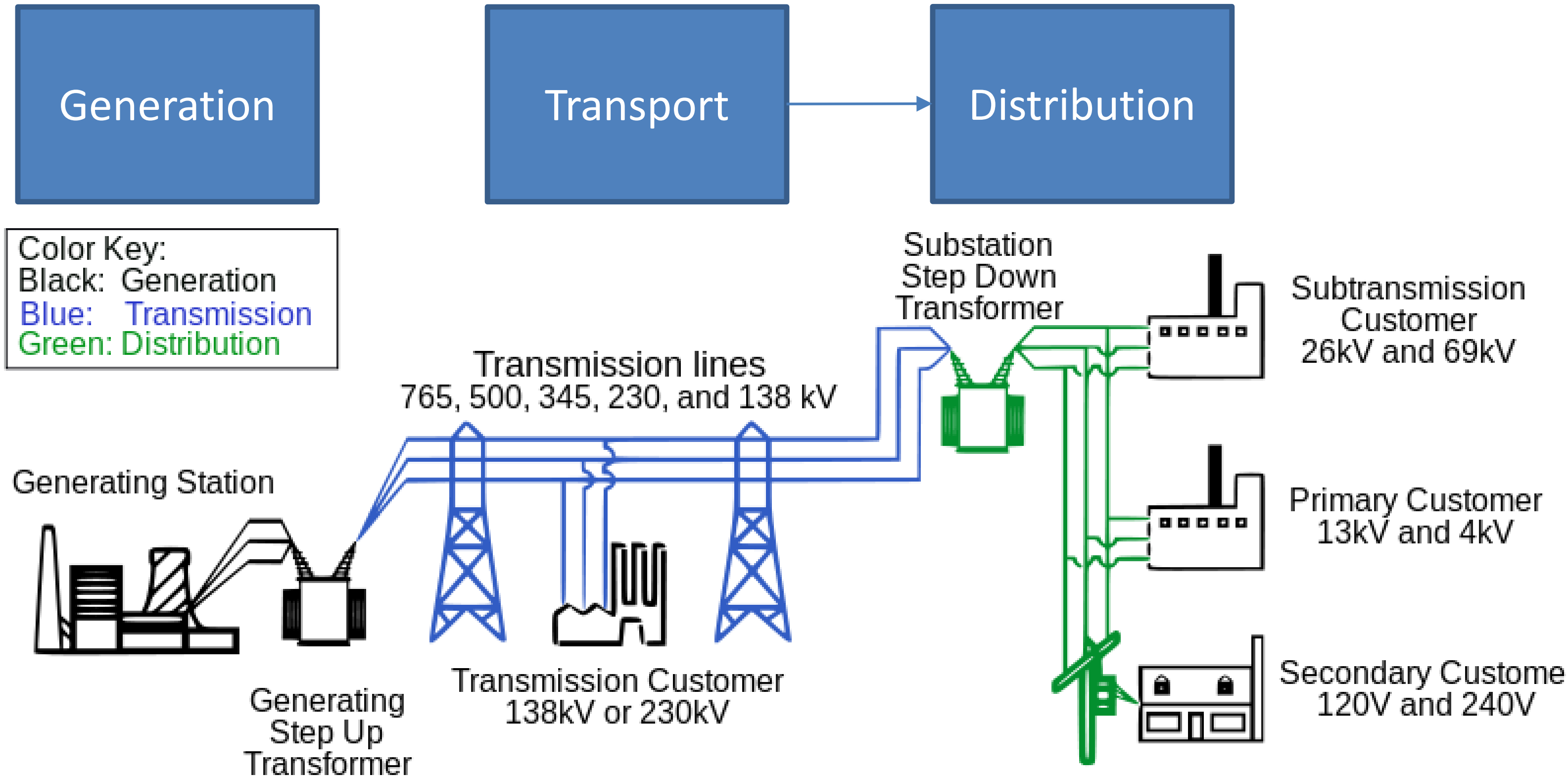
Monotone curve of electricity prices (Spain 2015) vs cumulative number of hours
Annual number of hours with price greater than certain value

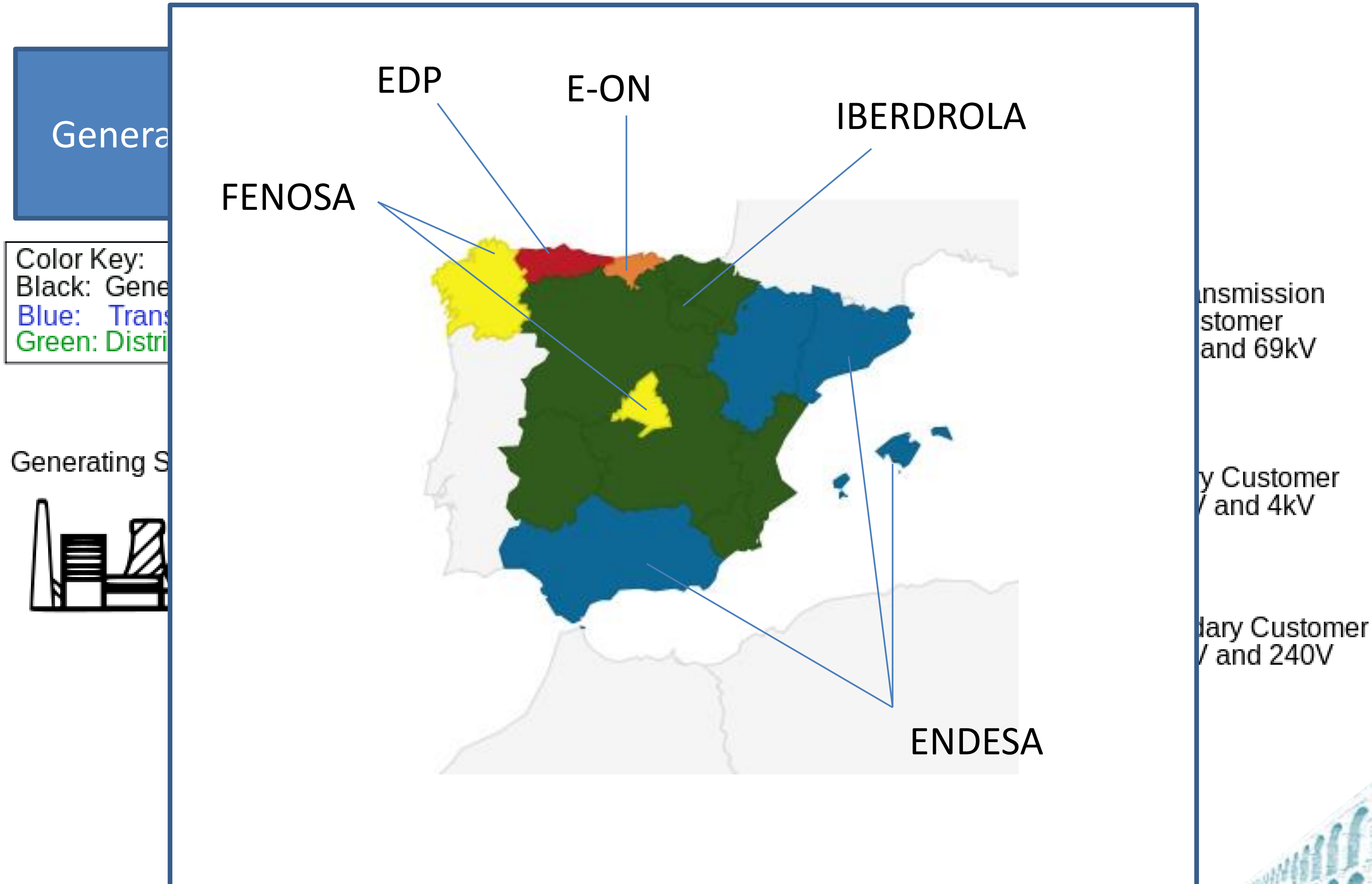
Expected number of hours with electricity prices >= G




Commercialization
Generation
HV
Transport
HV
Distribution
HV-MV
LV
Industries & Services
End consumers
Thermal generation
Hydro generation
Wind power
REE Control centre
Transport network
Transport substation
Distribution network
Distribution substation
Residential consumption (low voltage)
Industrial consumption (high voltage)

The electrical market. The liberalized situation. Actors.




EDP
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FENOSA
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Color Key:
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Blue: Trans
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OUTLINE

Blackout risk in the distribution network

<u>Point at risk</u>

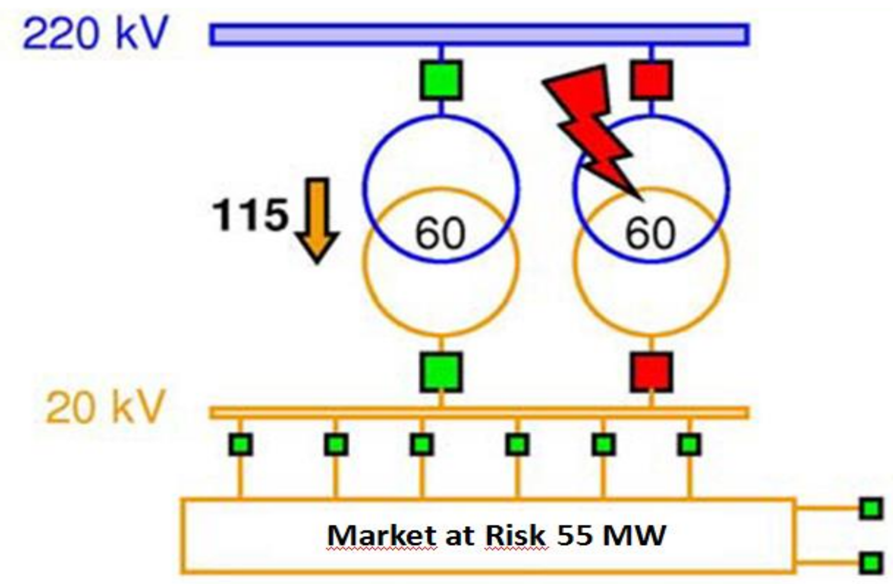
In the electrical distribution business, critical points (or points of risk) are those elements in which **the network does not verify the planning criteria. Contrary to transmission (transportation) networks, distribution networks haven´t had so far a set of official** planning criteria, although each distribution company develops its own planning criteria which, once authorized by the Administration, **are mandatory**.

<u>Planning criteria</u>

The most common accepted criterion for planning HV (High Voltage) and substation networks is the so called **"N-1" criterion**. This criterion requires **that the system musts cover the simple failure of any HV element (overhead line, cable or transformer) along all the hours of the year**, i.e. **it obliges to oversize the installation in order to cover the demand even if a component fails.**

To illustrate this definition, see Figure 1, suppose that a substation 220/20 kV is being analyzed. In this substation there are two 60 MVA transformers which feed a market with a peak demand of 115 MW. In a full availability situation, the substation can achieve a demand up to 120 MW (full capacity power). In the case of a 60 MW transformer failure, the maximum power that the substation can feed is of 60 MW.

As the market demand is, in the considered case, 115 MW, **the consequence of this failure will be a 55 MW blackout**, this amount is called **power at risk.**



Regulation for new investments in the distribution network

As the electricity supply is an activity of public interest, each new installation (in order to fulfil the demand or avoiding risk) is supported by public founds according to the next rules:

The investment needed to solve the risk (installing new transformers or extending lines), **once approved**, is refunded to the distribution company from authorities during 40 years:

1) Interests of the investments at an annual rate of 6.5% following a decreasing remuneration law :

$$Investment\left(1-\frac{t}{40}\right)(0.065)\quad t=1\ldots 39$$

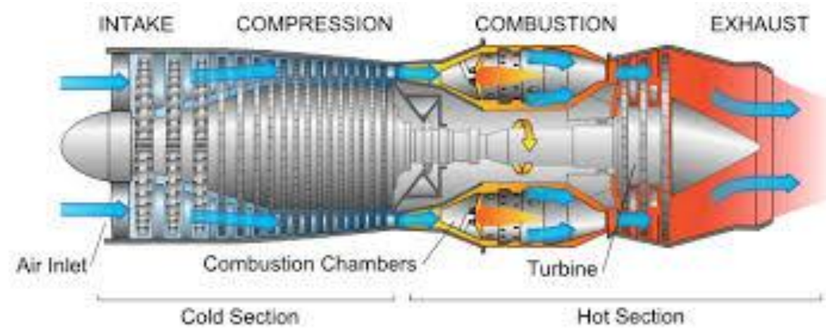
2) These quantities have to be increased in a percentage of 2% over the investment that considers the need of maintenance during 40 years.

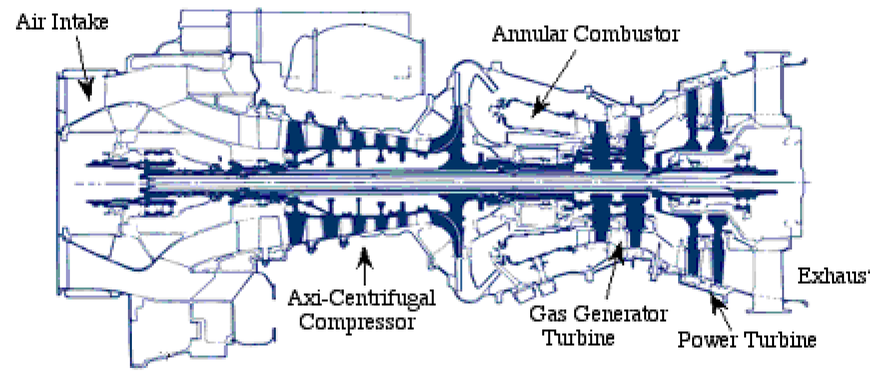
3) The refund affects also the depreciation computed along a time horizon of 40 years at a constant value.

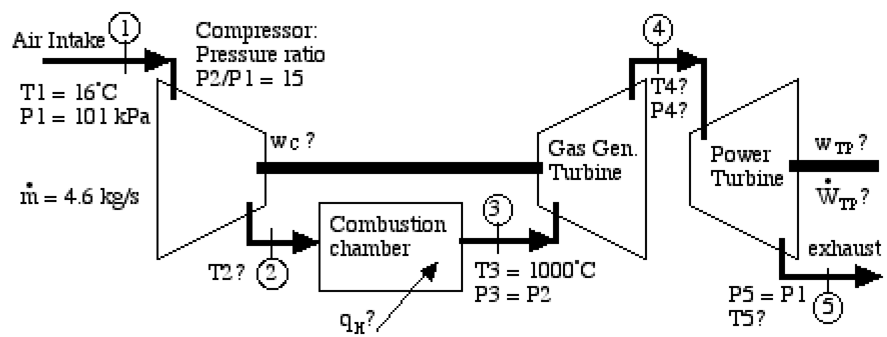
$$\frac{Investment}{40}\qquad t=1..40$$

OUTLINE

The basic operation of the gas turbine is similar to the steam machine, unless instead of water the air is used. The fresh air of the ambience flows across a compressor that raises it to a high pressure. Then energy is added dispersing fuel in the same one and burning it so that the combustion generates a flow of high temperature. This gas of high temperature and pressure enters a turbine, where it expands diminishing the exit pressure, producing the movement of the axis during the process. The work of this axis of the turbine is to move the compressor and other devices like electrical generators that can be connected.







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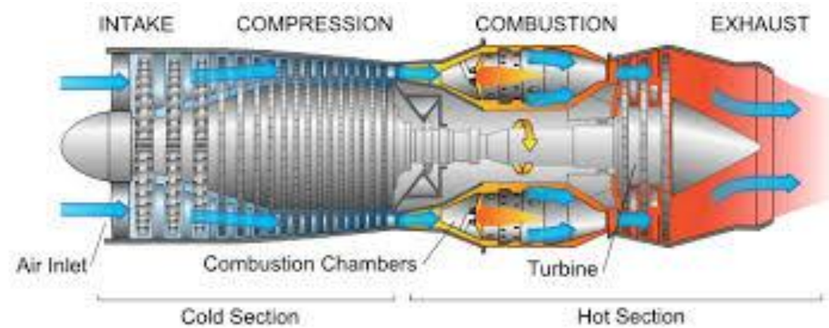
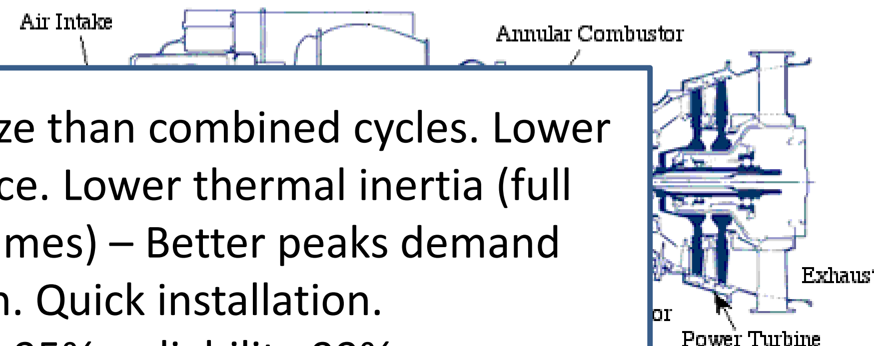
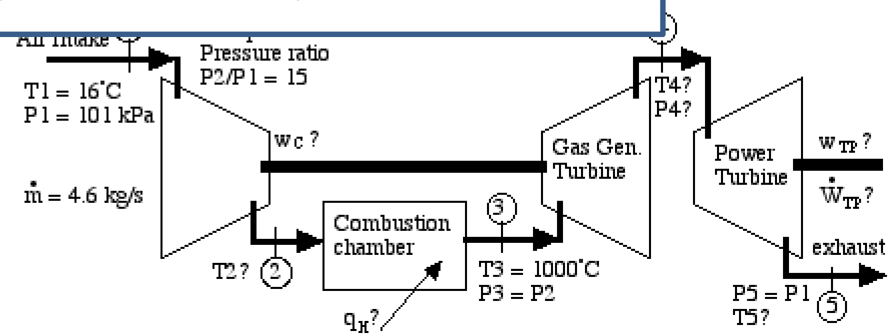




Advantages: Lower size than combined cycles. Lower need of maintenance. Lower thermal inertia (full capacity in lower times) – Better peaks demand regulation. Quick installation.
Availability 95%, reliability 99%.



Distributed generation

Installation of energy generation sources (gas turbines) in a distributed way at certain points in the network with the aim of mitigating the blackout risk at points at risk. Eventually, when no blackout situations exist, these sources can produce electricity and shell it in the market.

Problem statement

Given a set of points at risk and a set of feasible gas turbines the planning problem consists in determining the convenience of installing turbines at several points at risk, choosing the appropriate turbine model and the year of installation, taking into account turbines supply restrictions (manufacturers capacity) while maximizing the Net Expected Profit (Net Present Value of investment). To this end, , the existence of an incentive to encourage DG about the location of turbines near the power at risk points in the network, namely network remuneration, is considered.

In order to analyze the possible strategies derived from the use of gas turbine distributed generation, two different mixed integer programming optimization planning models have been developed (Paper in Energy, forthcoming).

The Distribution System operator point of view

The first one (M1) (**Not illustrated in this presentation**) imposes a global network agreement among DSO and generation companies in order to cover all the point at risk in the network. As the model M1 ensures the covering of all point at risk with power at risk lower than 50 MW, and the partial covering of risk points with power at risk above 50 MW, **this model mainly represents the interest of DSO and can be viewed as a "global risk solving" model.**

Generators point of view

A second model, **showed in this presentation**, M2, leaves full freedom to DG's to choose where install a source of generation on the locations proposed by the distributor and, in this case, what type of turbine, attending its own interests. The model provides the temporal installation plan of turbines along certain planning horizon, maximizing also the net present value under turbine supply limits. As the model M2 relaxes the covering obligations of M1, solutions are guided by the expected profit of DG's. Thus, **this model mainly represents the interest of DG's and can be viewed as a "business opportunity" model.**

Sets

$\hat{T}$	Number of periods (years) needed to complete the installation of power turbines).
$\bar{T}$	Number of periods needed to amortize investments (usually 40 years).
T	Total planning horizon, $T = \{1,2,\dots,\hat{T}+\bar{T}\}$.
$\acute{T}$	Number of years employed to compute investment analysis (usually 25 years).
N	Set of power solutions (gas turbine models) with nominal power up to $\{1,2,\dots,NT\}$.

Data

C_i	Cost of turbine model $i \in N$ [€].
P_i	Power of turbin… $i \in N$ $[MW]$.
E_i	Efficiency of t… el $i \in N$ [%].
D	Set of points at … lectrical distribution network, $D = \{1,2,\dots,ND\}$.
PD_j	Electric power at … ion $j \in D$ $[MW]$.
CS_j	Total estimated cos… power at risk on location $j \in D$. Represents the the deficiency j by … direct intervention on the distribution r conventional methods
G	Price of gas $[€/kWh]$.

Initial calculations

MC_i	Marginal cost of turb… N obtained from the price of gas and the turb $MC_i = G/E_i \quad i \in N$.
CM_i	Cumulative margin of turbine model $i \in N$ $\left[{€}/_{kW\ year}\right]$.
AM_i	Average margin of turbine model $i \in N$ $[€/kWh]$.
TM_i	Total annual margin of turbine model $i \in N$ $[€/year]$.
H_i	Number of hours per year of use of turbine model $i \in N$ attending historica provided by the power monotone curve $[h/year]$.
$\hat{P}_k$	Forecast price of electricity per hour in the monotone curve of prices fc $\{1,2,\dots K\}[€/kWh]$.
CH_k	Cumulative number of hours at price <= P_k in the cumulative curve of electric $\{1,2,\dots K\}$ $[h/year]$.

Parameters

α	Parameter of remuneration. Represents a % of the cost of solving each pow location. It can be viewed as an incentive to the Distributed Operation Cor installation of turbines close to the risk point instead of installing in a more prof
r	Discount rate.
β	Additional charge due to engineering analysis, turbine installation and loyal per
POM	Percentage of the network maintenance costs
MT_{it}	Maximum number of turbines of model i supplied in year t by the manufacture
ρ	Regulated rate of remuneration. Accordingly to the Spanish regulation, distribut are remunerated taken into account the investment costs (depreciation and remu assets) at a given rate.
Φ	Taxes (%)
μ	Maintenance extra cost of installed turbines per year, percentage over investme

Variables

$$x_{ijt} = \begin{cases} 1 \text{ if the turbine model } i \in N \text{ is installed in year } t \in T \\ \quad \text{to solve the power at risk of location } j \in D, \\ 0 \text{ otherwise}, \end{cases} \quad i \in N, j \in D, t \in \hat{T}.$$

$$\tau_j = \begin{cases} 1 \text{ if the installed power at point of risk } j \\ \quad \text{is greater than } PD_j \left(PD_j \le PD^{max} \right), \\ 0 \text{ otherwise}, \end{cases} \quad j \in D.$$

In Spain, power installations bigger than 50 MW require environmental studies and a set of bureaucratic measures that ,in practice, do impossible the use of distributed generation as a realistic alternative.

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$$j \in D.$$

In Spain, power installations bigger than 50 MW require environmental studies and a set of bureaucratic measures that ,in practice, do impossible the use of distributed generation as a realistic alternative.

Initial calculations for turbine model *i*

Number of profotible hours per year for turbine model i..

$$H_i = \sum_{k=2:P_k \geq MC_i}^{K} (CH_k - CH_{k-1}), \quad \forall\, i = 1, \ldots, N. \quad [h/year]$$

Cumulative margin of turbine model i.

$$CM_i = \sum_{k=2:P_k \geq M_i}^{K} (CH_k - CH_{k-1})(\hat{P}_k - MC_i), \quad \forall\, i = 1, \ldots, N. \quad \left[{€}/{kW\ year}\right]$$

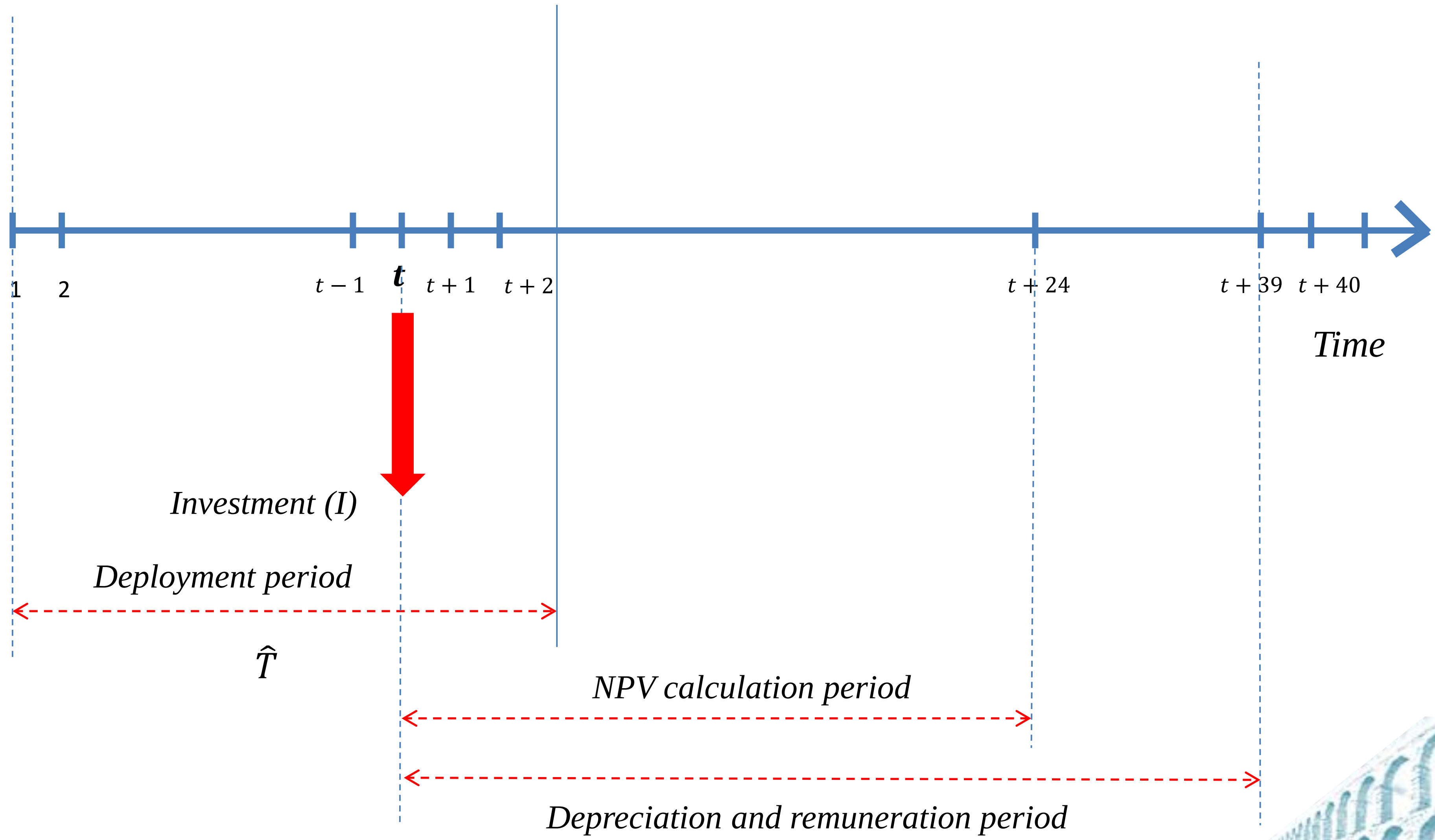
Average margin of turbine model i.

$$AM_i = \frac{CM_i}{H_i}, \quad \forall\, i = 1, \ldots, N. \quad \left[{€}/{kWh}\right]$$

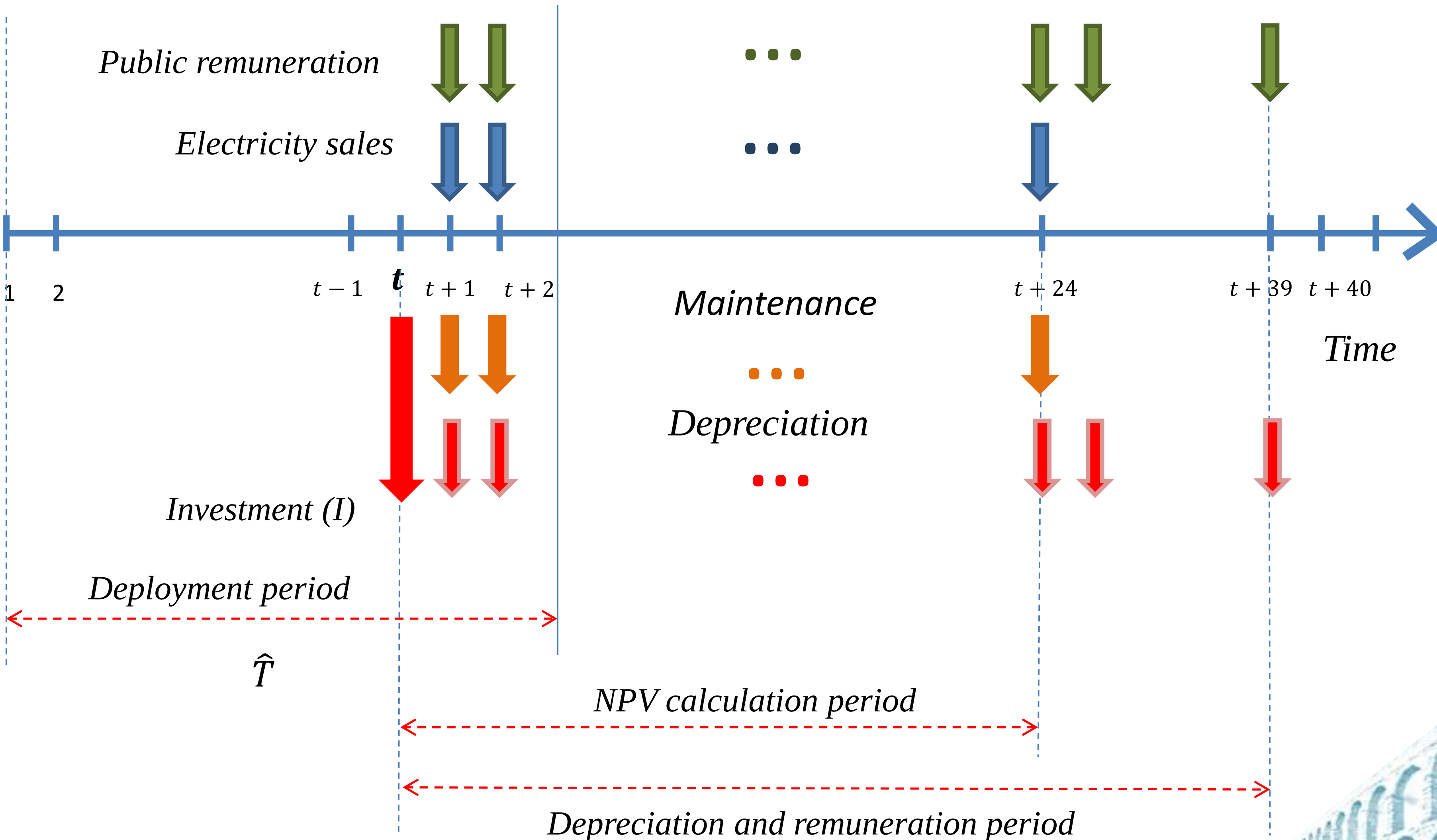
Total margin (expected profit) due to electricity sales of turbine model i.

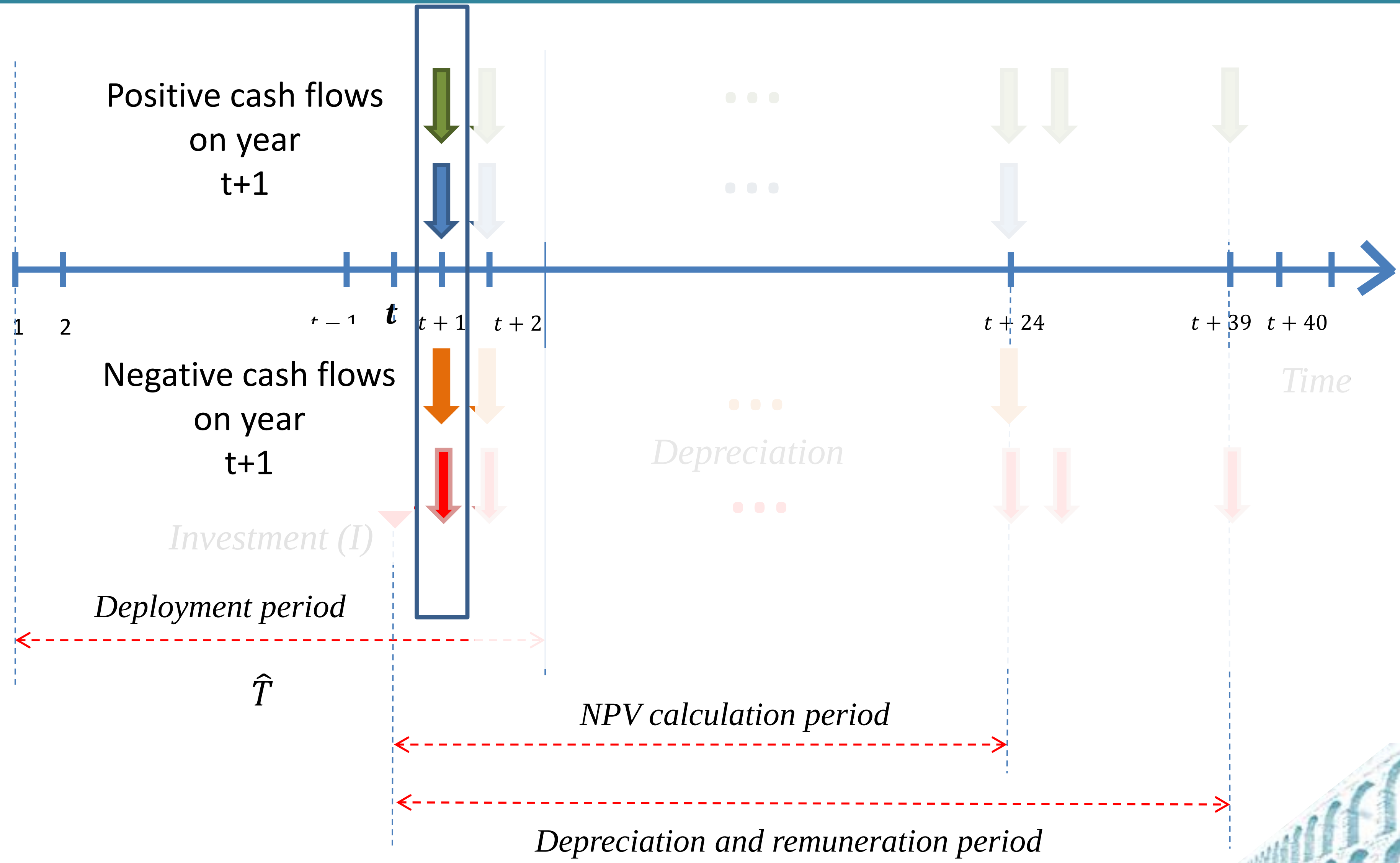
$$TM_i = AM_i H_i P_i = CM_i P_i, \quad \forall\, i = 1, \ldots, N. \quad \left[{€}/{year}\right]$$

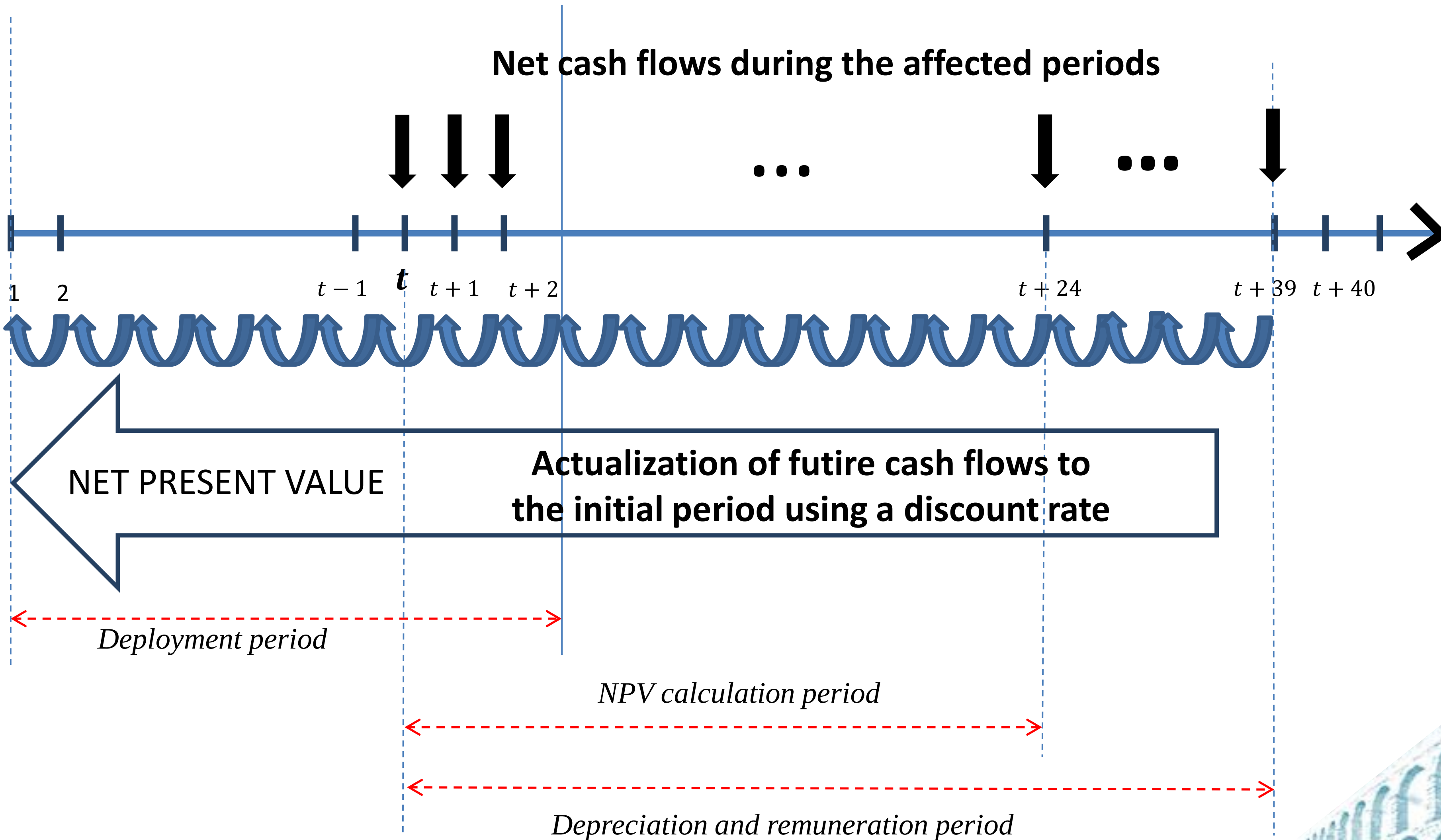
THE PROBLEM: The planning periods



THE PROBLEM: Positive and negative flows




Positive cash flows
on year
t+1
1
2
t − 1
t
t + 1
t + 2
t + 24
t + 39
t + 40
Time
Negative cash flows
on year
t+1
Depreciation
Investment (I)
Deployment period
$\hat{T}$
NPV calculation period
Depreciation and remuneration period


Net cash flows during the affected periods
…
…
1
2
t − 1
t
t + 1
t + 2
t + 24
t + 39
t + 40
NET PRESENT VALUE
Actualization of futire cash flows to
the initial period using a discount rate
Deployment period
NPV calculation period
Depreciation and remuneration period

$$Max\ NPV^T$$

Maximization of the total net present value of investments

st:

$$\sum_{t=1}^{\hat{T}} \sum_{i \in N} P_i x_{ijt} \leq PD^{max}, \qquad \forall j \in D.$$

Environmental constraint. Instalked power less tan 50 Mw.

$$\sum_{t=1}^{\hat{T}} \sum_{i \in N} x_{ijt} \leq 1, \qquad \forall\, j \in D.$$

No more tan one turbine model per location (technical constraint)

$$\sum_{j \in D} x_{ijt} \leq MT_{it}, \qquad \forall\, t = 1, \dots, \hat{T}, i \in N.$$

Supply limitation (manufacturers' capacity)

Computing public remueration as a function of α

$$RI_{tj} - M_j\,\tau_j \le \rho\,\alpha\,CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \frac{1}{19.5} \sum_{i \in N} \frac{P_i\,x_{ijs}}{PD_j} \left(1 - \frac{t-s}{40}\right) \le RI_{tj} + M_j\,\tau_j,$$

$$\forall j \in D:\ PD_j \le PD^{max}, t = 1, \dots, T, \qquad [^{€}/_{year}]$$

$$RI_{tj} - M_j(1-\tau_j) \le \rho\,\alpha\,CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \frac{1}{19.5} \sum_{i \in N} x_{ijs} \left(1 - \frac{t-s}{40}\right) \le RI_{tj} + M_j(1-\tau_j),$$

$$\forall j \in D:\ PD_j \le PD^{max}, t = 1, \dots, T. \qquad [^{€}/_{year}]$$

Public remuneration corresponding to investments.
Point at risk j, year t.

$$MR_{tj} - M_j\,\tau_j \le \frac{\rho\,\alpha\,POM}{40} CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \sum_{i \in N} \frac{P_i\,x_{ijs}}{PD_j} \le MR_{tj} + M_j\,\tau_j,$$

$$\forall j \in D: PD_j \le PD^{max}, t = 1, \dots, T, \qquad [^{€}/_{year}]$$

$$MR_{tj} - M_j(1-\tau_j) \le \frac{\rho\,\alpha\,POM}{40} CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \sum_{i \in N} x_{ijs} \le MR_{tj} + M_j(1-\tau_j),$$

$$\forall j \in D: PD_j \le PD^{max}, t = 1, \dots, T. \qquad [^{€}/_{year}]$$

Public remuneration corresponding to maintenance.
Point at risk j, year t.

$$AR_{tj} - M_j\,\tau_j \leq \frac{\rho\,\alpha}{40} CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \sum_{i \in N} \frac{P_i\,x_{ijs}}{PD_j} \leq AR_{tj} + M_j\,\tau_j,$$

$$\forall j \in D{:}\, PD_j \leq PD^{max}, t = 1, \dots, T, \qquad [€/_{year}]$$

$$AR_{tj} - M_j(1-\tau_j) \leq \frac{\rho\,\alpha}{40} CS_j \sum_{s=\max(1,t-40)}^{\min(t,\hat{T})} \sum_{i \in N} x_{ijs} \leq AR_{tj} + M_j(1-\tau_j),$$

$$\forall j \in D{:}\, PD_j \leq PD^{max}, t = 1, \dots, T. \qquad [€/_{year}]$$

Public remuneration corresponding to depreciation.
Point at risk j, year t.

Relationships between location/selection variables and installed power variables

$$-PD^{max}(1-\tau_j) \leq \sum_{i \in N} \sum_{t \in \hat{T}} P_i\,x_{ijt} - PD_j \leq PD^{max}\tau_j, \qquad \forall j \in D{:}\; PD_j \leq PD^{max},$$

Computing negative flows

$$I_i = C_i(1+\beta), \qquad \forall\, i = 1, \dots, N. \; [€]$$

Total cost of turbine model i

$$I_{jt} = \sum_{i \in N} C_i\,(1+\beta)\, x_{ijt} = \sum_{i \in N} I_i\, x_{ijt}, \quad \forall\, j \in D, t = 1, \dots, \hat{T}. \quad [€/year]$$

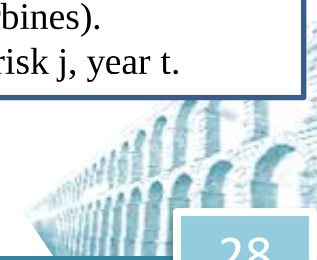
Investments per year.
Point at risk j, year t.

$$OM_{jt} = \sum_{s=\max(t-24,0)}^{t} I_{js}.\mu\,, \qquad \forall j \in D, t = 1, \dots, \acute{T}. \; [€/year]$$

Maintenance of equipments (turbines).
Point at risk j, year t.

$$A_{jt} = \sum_{s=\max(t-39,0)}^{t} \frac{I_{js}}{40}, \quad \forall j \in D, t = 1, \dots, T. \; [€/year]$$

Depreciation of investments (turbines).
Point at risk j, year t.



Computing profit before taxes and cash flows

$$BAIT_{jt} = RI_{tj} + AR_{tj} + MR_{tj} + \sum_{i \in N} x_{ijt} TM_i - (A_{jt} + OM_{jt} + I_{jt}), \quad \forall j \in D, t \leq \acute{T}$$

$$BAIT_{jt} = AR_{tj}, \quad \forall j \in D, \acute{T} < t \leq \hat{T} + \bar{T}. \quad [€/year]$$

Profit before taxes.
Point at risk j, year t.

$$CF_{jt} = BAIT_{jt}(1 - \phi) + A_{jt}, \quad \forall j \in D, t = 1 \dots \bar{T}. \quad [€/year]$$

Cash flow computation.
Point at risk j, year t.

$$NPV_j(x_{ijt}) = \sum_{t=1}^{T} \frac{CF_{jt}}{(1+r)^t}, \quad \forall j \in D. \quad [€]$$

Cash flow actualization to the first period.
Point at risk j

$$NPV^T = \sum_{j \in D} NPV_j. \quad [€]$$

Total net present value, summation over all points at risk

OUTLINE

3

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ILLUSTRATION: Turbine Models

Information about gas turbines characteristics has been taken from the Gas Turbine World Handbook 2014-15 (2015), where there is full information of gas turbines and combined cycles from different manufacturers. Next table represents the scatter plots of the attributes ‘cost per kW’ and ‘efficiency’ versus the ‘turbine power’ for the turbine models currently in the market. Due to environmental constraints, only turbines with nominal power less than 50 MW are considered.

Number	Model	€/kW	Efficiency	ISO Base Rating (kW)
1	C200	1,100	33.1%	200
2	M1A-170	912	26.8%	1,700
3	OP16-3B	885	26.9%	1,910
4	Centaur 40	853	27.9%	3,515
5	501-KB5	834	29.0%	3,897
6	Centaur 50	809	29.3%	4,600
7	501-KB7S	801	31.5%	5,245
8	SGT-100	787	31.0%	5,400
9	Taurus 60	769	31.5%	5,670
10	Taurus 65	722	32.9%	6,300
11	SGT-300	623	30.6%	7,901
12	Taurus 70	642	34.3%	7,965
13	GE10-1	533	31.4%	11,250
14	Mars 100	581	32.9%	11,350
15	GTU-12PG-2	528	32.6%	12,300
16	SGT-400	524	35.4%	14,326
17	Titan 130	552	35.2%	15,000
18	LM1800e -High	555	34.8%	17,768
19	SGT-500	525	33.7%	19,064
20	Titan 250	529	38.9%	21,745
21	LM2500PJ	558	35.4%	22,417
22	SGT-600	470	33.6%	24,480
23	LM2500PE	504	35.1%	24,820
24	1X FT8 SP25 OLN	511	38.1%	25,455
25	RB211-GT62 OLE	389	37.5%	29,845
26	1 x FT8 SP30	401	36.8%	30,850
27	MS5002E	405	35.0%	31,100
28	LM2500+ PK	432	36.9%	31,841
29	LM2500+ PR	468	38.8%	31,873
30	RB211-GT61 DLE	387	39.3%	32,130
31	SGT-700	366	37.2%	32,820
32	PGT25+G4	401	40.0%	33,057
33	LM2500+ G4 RD	435	39.2%	34,540
34	SGT-750	392	39.5%	37,031
35	H-25(35)	363	35.0%	37,690
36	LM6000PF	449	41.7%	43,069
37	6B.03	403	33.5%	44,000
38	LM6000PF Sprint	414	42.0%	48,675
39	SGT-800	356	38.3%	50,500
40	LM6000PG	396	41.9%	51,204
41	2xFT8 SP50 DLN	435	38.3%	51,235
42	LM6000PH	425	41.9%	51,438

Information about network risk in Spain has been provided by a Spanish DSO; this network represents a significant portion (close to 50 %) of the total points at risk in the Spanish network. In total, 80 critical points have been characterized. For each point (see Table 2), the power at risk, the investment needed to eliminate that risk (by expanding the network or installing new transformers) and the type of risk (Transformer or line problem) are shown.

Number	Power at risk (MW)	Investment (€)	Number	Power at risk (MW)	Investment (€)	Number	Power at risk (MW)	Investment (€)
Type Line			Type Line			Type Transformer		
1	10.5	40,000	**30**	10.2	1,547,522	**52**	14.7	155,000
2	41.3	320,217	**31**	18.9	3,060,716	**53**	22.3	501,517
3	42	360,862	**32**	71.8	11,681,945	**54**	16.6	574,904
4	211.7	2,934,635	**33**	37.9	6,314,980	**55**	46.0	2,052,583
5	158.9	2,258,064	**34**	14.8	2,555,310	**56**	5.3	276,969
6	102.7	1,782,144	**35**	15.3	2,750,564	**57**	5.2	327,774
7	117.8	2,349,005	**36**	27.2	5,190,109	**58**	12.5	796,195
8	142.4	3,120,702	**37**	15.3	3,000,769	**59**	14.7	941,260
9	25.1	625,636	**38**	19.5	3,919,657	**60**	8.8	735,281
10	38.5	999,090	**39**	16.1	3,549,418	**61**	7.7	705,169
11	61.8	3,005,016	**40**	7.4	1,788,735	**62**	10.3	952,807
12	31.7	1,704,237	**41**	9.2	2,284,435	**63**	16.0	1,609,980
13	111.7	6,926,217	**42**	9.6	2,440,821	**64**	19.3	1,965,656
14	25.5	1,588,105	**43**	13	3,879,367	**65**	8.9	941,260
15	44.9	2,828,500	**44**	16.9	5,146,912	**66**	5.2	601,635
16	21.6	1,574,073	**45**	15.6	4,976,243	**67**	7.1	834,426
17	56.4	4,116,055	**46**	10.95	3,619,076	**68**	5.9	737,806
18	74.1	5,432,785	**47**	6.6	2,565,240	**69**	7.1	884,232
19	23.1	1,918,080	**48**	7.2	3,066,607	**70**	6.6	982,596
20	31.3	2,637,000	**49**	11.5	5,049,054	**71**	5.6	945,876
21	32.2	3,045,631	**50**	8	4,100,915	**72**	6.7	1,228,754
22	32.9	3,510,061	**51**	6.3	4,923,524	**73**	5.2	964,698
23	11.52	1,239,960				**74**	5.1	955,179
24	15	1,983,187				**75**	8.7	1,758,259
25	56.8	7,645,862				**76**	17.0	4,613,795
26	16	2,225,390				**77**	7.2	2,247,561
27	20.6	2,872,298				**78**	8.9	2,910,499
28	24.5	3,435,860				**79**	11.4	5,859,722
29	14.2	2,049,677				**80**	6.4	7,114,958

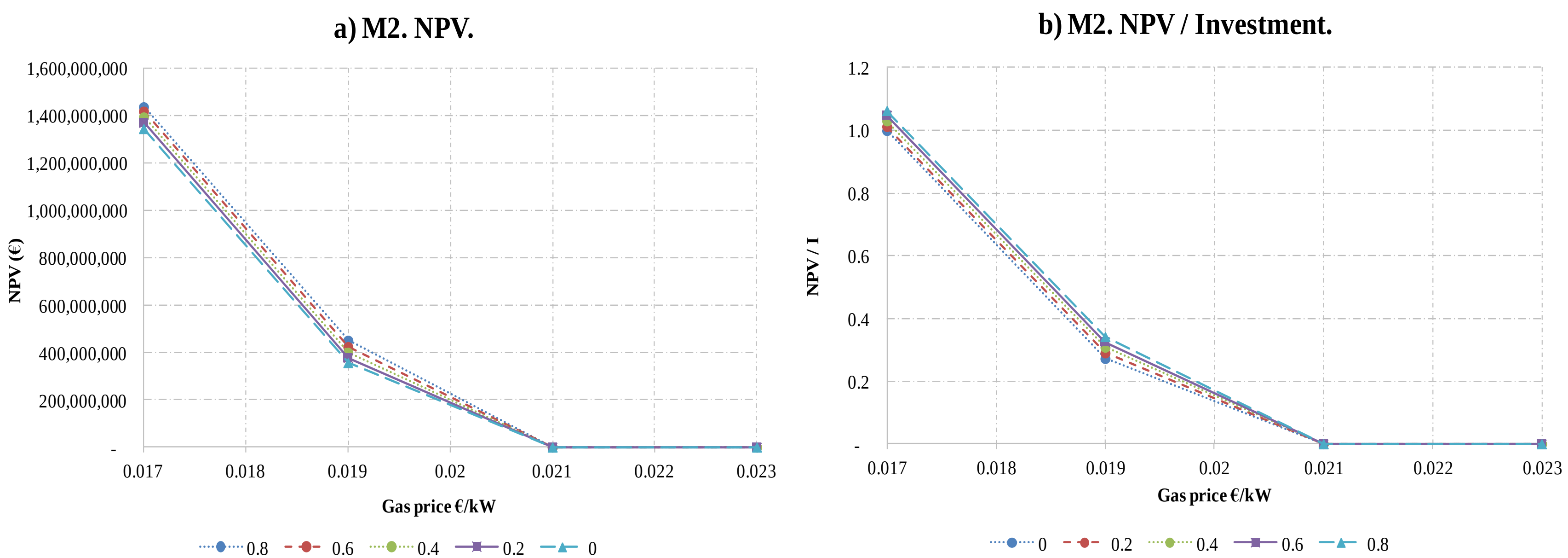
The model which gives a complete freedom to DG's in the selection of the most convenient locations for installing turbines, as well as in the choice of the most appropriate turbine models. For this scenario, the model contains **64,730 constraints** and **66,642** variables, **33,669** of them, binary. The model has been coded in GAMS (GAMS v24.3) and solved with CPLEX v12.5 (1200 secs, Intel i7, 2.6 GHz, 8GB RAM).

Exp. No. 1. (**No supply limits**) Testing coherence

The constraint corresponding to the maximum number of supplied turbines by year is relaxed by fixing this limit to the number of risk points (80). **As expected**, in this case, if the gas price is lower than 0.020 €/kWh, i.e. (for the cases G=0.017 and G=0.019), and considering a remuneration parameter $\alpha \geq 0.4$ (cases with α =0.4, α =0.6, α =0.8) **the DG install the turbine model 40 at all the risk points**.
Note that turbine model 40 has a nominal power of 51204 kW and an efficiency of 41.09%. **Although the power of models 41 and 42 is higher**, the model 41 has a lower efficiency and it is more expensive whereas the model 42 has the same efficiency but is also more expensive**. In comparison with the turbine model 42, the extra remuneration obtaining for installing a bit more power do not compensate the cost of the turbine**

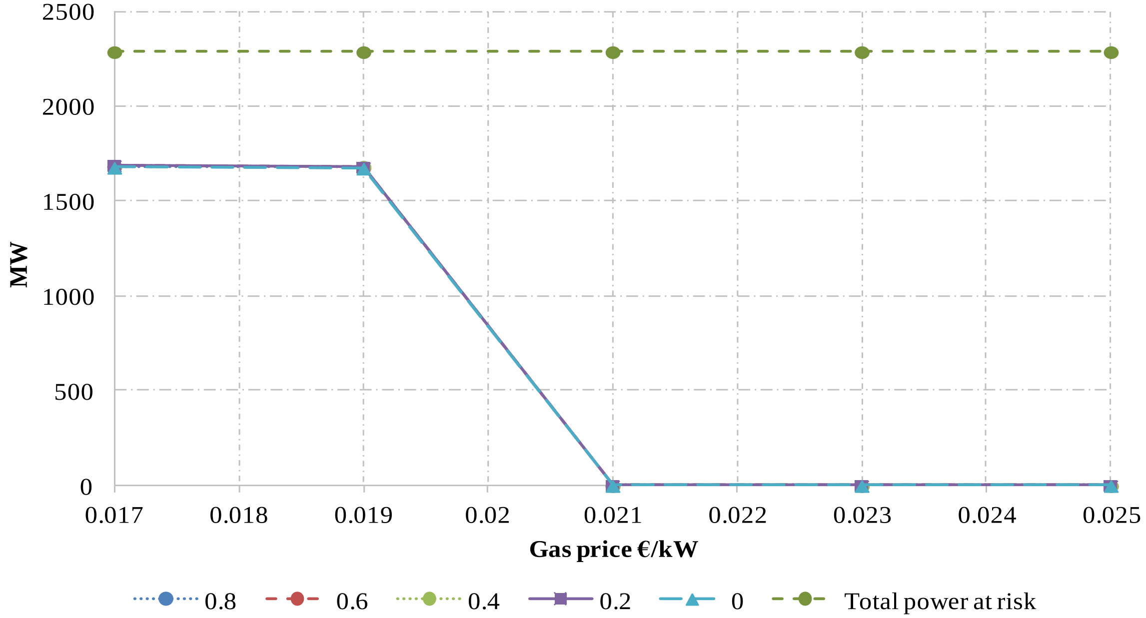
Exp. No. 2. (**Supply limit of 5 turbines per year – all models**)

The previous experiment is repeated **by varying the price of gas** for **different values of the remuneration parameter α**, in this occasion from 0 to 80% by incrementing in 20% each time and considering a maximum supply of 5 turbines/year for each model.



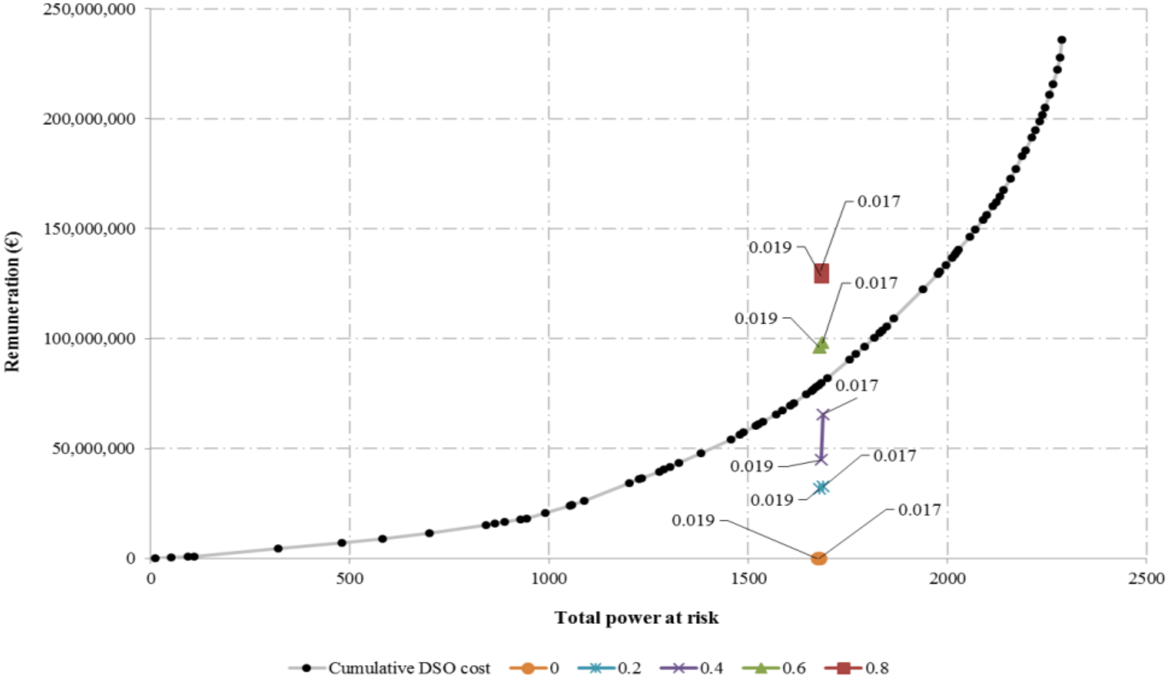
Net present value by varying the remuneration parameter.

Total power at risk mitigated for different scenarios by varying the price of gas and the remuneration parameter. For all the values of α, the residual power at risk is the initial one if the price of gas exceeds 0.021 €/kW, i.e. DG's will decide to not enter in the market. As shown, a variation in the parameter



Mitigated risk.

A comparison between solving strategies cost (conventional methods versus gas turbine DG model M2) is presented for different values of the remuneration parameter α, concretely, 0.0, 0.4, 0.6 and 0.8. As illustrated, remuneration values of 0.8 and 0.6 outperform the solving cost by conventional methods represented by the "Cumulative DSO Cost" (i.e. DG's will select power at risk points with the highest risk in order to obtain a good remuneration, those where the cost of solving each MW are higher for traditional methods). **A value of $\alpha = 0.4$ (and also values of 0.2 and no remuneration) give rise to lower cost than using conventional methods**. In case of no remuneration DG's enter the market whenever the price of gas is lower than 0.019 €\kW removing practically the same risk as in the rest of cases



Comparison of solving costs (conventional methods vs. gas turbine DG).

0.8									
G=0.019									
RP	**Y**	**M**	**PaR**	**Ins**	**RP**	**Y**	**M**	**PaR**	**Ins**
1	7	40	10.5	51.2	**41**	3	38	9.2	48.7
2	7	40	41.3	51.2	**42**	3	40	9.6	51.2
3	6	40	42	51.2	**43**	1	40	13	51.2
4	5	40	212	51.2	**44**	1	40	16.9	51.2
5	5	40	159	51.2	**45**	1	38	15.6	48.7
6	4	42	103	51.4	**46**	2	38	11	48.7
7	4	42	118	51.4	**47**	2	38	6.6	48.7
8	4	42	142	51.4	**48**	2	40	7.2	51.2
9	6	40	25.1	51.2	**49**	1	40	11.5	51.2
10	4	40	38.5	51.2	**50**	2	38	8	48.7
11	3	42	61.8	51.4	**51**	1	38	6.3	48.7
12	3	38	31.7	48.7	**52**	7	40	14.7	51.2
13	2	42	112	51.4	**53**	6	40	22.3	51.2
14	3	42	25.5	51.4	**54**	6	40	16.6	51.2
15	1	36	44.9	43.1	**55**	1	36	46	43.1
16	4	42	21.6	51.4	**56**	7	40	5.27	51.2
17	1	42	56.4	51.4	**57**	7	40	5.23	51.2
18	1	42	74.1	51.4	**58**	5	38	12.6	48.7
19	3	40	23.1	51.2	**59**	4	40	14.7	51.2
20	2	42	31.3	51.4	**60**	5	38	8.77	48.7
21	2	42	32.2	51.4	**61**	5	38	7.72	48.7
22	2	38	32.9	48.7	**62**	4	38	10.3	48.7
23	4	40	11.5	51.2	**63**	3	42	16	51.4
24	3	40	15	51.2	**64**	3	38	19.3	48.7
25	1	42	56.8	51.4	**65**	4	38	8.89	48.7
26	3	42	16	51.4	**66**	6	40	5.17	51.2
27	2	40	20.6	51.2	**67**	5	40	7.08	51.2
28	2	42	24.5	51.4	**68**	5	40	5.91	51.2
29	3	42	14.2	51.4	**69**	5	40	7.07	51.2
30	4	40	10.2	51.2	**70**	4	42	6.62	51.4
31	2	40	18.9	51.2	**71**	4	38	5.56	48.7
32	1	42	71.8	51.4	**72**	4	40	6.7	51.2
33	1	42	37.9	51.4	**73**	4	38	5.17	48.7
34	3	38	14.8	48.7	**74**	4	38	5.08	48.7
35	2	38	15.3	48.7	**75**	3	40	8.72	51.2
36	1	40	27.2	51.2	**76**	1	40	17	51.2
37	2	40	15.3	51.2	**77**	3	40	7.16	51.2
38	1	38	19.5	48.7	**78**	2	40	8.93	51.2
39	2	42	16.1	51.4	**79**	1	38	11.4	48.7
40	3	38	7.4	48.7	**80**	1	38	6.38	48.7

0.4									
G=0.019									
RP	**Y**	**M**	**PaR**	**Ins**	**RP**	**Y**	**M**	**PaR**	**Ins**
1	7	40	10.5	51.2	**41**	3	38	9.2	48.7
2	7	40	41.3	51.2	**43**	1	40	13	51.2
3	6	40	42	51.2	**44**	1	40	16.9	51.2
4	6	40	212	51.2	**45**	1	42	15.6	51.4
5	5	40	159	51.2	**46**	2	40	11	51.2
6	4	42	103	51.4	**47**	3	38	6.6	48.7
7	4	42	118	51.4	**48**	2	38	7.2	48.7
8	4	42	142	51.4	**49**	1	38	11.5	48.7
9	5	38	25.1	48.7	**50**	1	40	8	51.2
10	4	40	38.5	51.2	**51**	1	40	6.3	51.2
11	3	42	61.8	51.4	**52**	7	40	14.7	51.2
12	3	40	31.7	51.2	**53**	6	40	22.3	51.2
13	2	42	112	51.4	**54**	6	40	16.6	51.2
14	4	42	25.5	51.4	**55**	3	42	46	51.4
15	2	42	44.9	51.4	**56**	7	40	5.27	51.2
16	4	40	21.6	51.2	**57**	7	40	5.23	51.2
17	2	42	56.4	51.4	**58**	5	38	12.6	48.7
18	1	42	74.1	51.4	**59**	4	40	14.7	51.2
19	3	42	23.1	51.4	**60**	5	38	8.77	48.7
20	2	40	31.3	51.2	**61**	5	40	7.72	51.2
21	2	38	32.2	48.7	**62**	4	40	10.3	51.2
22	2	40	32.9	51.2	**63**	3	42	16	51.4
23	4	40	11.5	51.2	**64**	3	40	19.3	51.2
24	3	40	15	51.2	**65**	5	40	8.89	51.2
25	1	42	56.8	51.4	**66**	6	40	5.17	51.2
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27	2	42	20.6	51.4	**68**	5	38	5.91	48.7
28	2	38	24.5	48.7	**69**	5	40	7.07	51.2
29	3	40	14.2	51.2	**70**	4	38	6.62	48.7
30	4	42	10.2	51.4	**71**	4	38	5.56	48.7
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32	1	42	71.8	51.4	**73**	4	38	5.17	48.7
33	1	42	37.9	51.4	**74**	4	38	5.08	48.7
34	3	38	14.8	48.7	**75**	3	40	8.72	51.2
35	2	42	15.3	51.4	**76**	1	38	17	48.7
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37	2	38	15.3	48.7	**78**	2	38	8.93	48.7
38	1	38	19.5	48.7	**79**	1	38	11.4	48.7
39	2	40	16.1	51.2	**80**	1	38	6.38	48.7
40	3	38	7.4	48.7					

We include detailed solutions for two of the studies cases, corresponding to $\alpha = 0.8$ and 0.4 for G=0.019 €/kW. Column **'RP' represents the Risk Point number**, **'Y' denotes the year of installation and column 'M' the turbine model, 'PAR' corresponds to the power at risk and column 'Ins' is the installed power.**

Regarding the results, as might be expected**, the risk mitigated increases as the network contribution increases** (**higher values of α**), although the investment effort is not proportional to the risk eliminated. It is also interesting that all the selected turbines (36, 38, 40 and 42) correspond to different variations of the same model of LM600 turbine of General Electric, an aereoderivative gas turbine of high performance and latest technology.

Summary

	α	
	0.4	**0.8**
Powert at Risk (MW)	1,678	1,683
Network Contrinution '000 €	75,980	150,888
Number of Turbines	79	80
Model 42	20	20
Model 40	35	35
Model 38	24	23
Model 36	–	2
Totally mitigated risk points	66	67
Partially mitigated risk points	13	13

OUTLINE

In order to analyze the possible strategies derived from the use of gas turbine distributed generation, two different mixed integer programming optimization planning models have been developed. The first one (M1) (**Not illustrated in this presentation**) **mainly represents the interest of DSO and can be viewed as a "global risk solving" model.**

A second model, **showed in this presentation**, M2, leaves full freedom to DG's to choose where install a source of generation on the locations proposed by the distributor and, in this case, what type of turbine, attending its own interests. **This model mainly represents the interest of DG's and can be viewed as a "business opportunity" model.**

Both models provide the temporal installation plan of turbines along certain planning horizon, maximizing also the net present value under turbine supply limits.

In both cases**, DG's could be encouraged by DSO to install the appropriate generation power precisely at the points at risk in the network**, **using a regulated remuneration that incentives the selection of these points**. This remuneration could cover potential losses due to the gas price variability, aiming to DG's to cover, at least partially, several points at risk even when the total expected cumulative margin at these points is negative.

CONCLUSIONS

Although the proposed methodology is general, in order to illustrate its applicability, a distribution network containing a significant portion (close to 50 %) of the total points at risk in the Spanish network has been used as testing scenario. Different experiments are carried by varying the gas price and the remuneration factor.

We can conclude that, in order to diminish the total power at risk, it makes no sense that DSO contributes to the installation of the turbines, **but it is extremely important that the gas price remains low**. A remuneration lower than 50% can contribute to cover partially this issue (the gas price variability).

The contribution of the System Regulator could be to provide contracts for gas price coverage for those generators that install turbines at the points proposed by the DSO. To do this, **it will be necessary to develop a sufficiently broad gas future market**.

Exploring the possibility of applying the same model type but **using storage** cells (batteries) **to be charged at valley hours** (lower costs) and **shelling energy at peak hours** (bigger margin).

Modify the model to analyse the impact of the **temporal decommissioning of nuclear power plants in Spain** and its replacement by different generation technologies.

Thank you for your attention!.