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A. Parámetros de entrada

En este primer anexo, se detallan todos los parámetros de entrada tenidos en cuenta a lo largo de las experimentaciones realizadas. En primer lugar se detallan los parámetros iniciales característicos del global del sistema. En segundo lugar se detallan los parámetros característicos de los equipos de generación dando a la vez el potencial eólico para todos los puntos de consumo de todas las comunidades. En tercer lugar, se dan las características de los componentes generales de los sistemas de electrificación con que se trabaja. Para todos los casos, y siempre que es necesario, se da el detalle de los elementos tenidos en cuenta para cada componente.

Antes de detallar los parámetros, cabe destacar que los valores dados son válidos para la experimentación definitiva. En el caso de la experimentación preliminar, hay algunas ligeras modificaciones que si bien no afectan a los tiempos de cálculo pueden afectar a los resultados. De todos modos, al compararse entre sí los resultados de la experimentación preliminar y entre sí los de la experimentación definitiva, pero nunca compararse entre sí ambas experimentaciones, las variaciones de datos no afectan a las conclusiones que se extraen finalmente.

A.1. Parámetros característicos del global del sistema

Hay una serie de parámetros globales que afectan al conjunto del sistema.

- **Tensión:** la electricidad suministrada es a 220V, teniendo en consideración unos límites por fluctuaciones del sistema de $\pm 10V$.
- **Factor de descarga de las baterías:** 0,6.
- **Factor de simultaneidad:** 0,9.
- **Días de autonomía:** 2 días.
- **Máxima distancia entre dos puntos conectados por un conductor:** 1km.
- **Coste de un poste para los puntos finales de micro red:** 133\$.
- **Mínimo porcentaje de energía producida con equipos solares para cada punto de consumo:** 25%.
- **Mínimo porcentaje de energía producida con equipos eólicos para cada punto de consumo:** 0%.
- **Número mínimo de equipos de generación para abastecer a cada punto de consumo:** 2 equipos, ya sean solares, eólicos o una mezcla de ambas tecnologías.



A.2. Equipos de generación

Existen 2 tipos de equipos de generación: aerogeneradores y paneles fotovoltaicos. En ambos casos existen 2 elementos importantes a detallar: las características técnicas y los potenciales obtenidos – tras la evaluación de recursos – en cada punto de consumo y para cada tipo de equipo.

A.2.1. Aerogeneradores y potencial eólico

Se utilizan 4 tipos de aerogeneradores, los cuales han desarrollado – o están pendientes de desarrollar – por la Universidad Politécnica de Cataluña junto con ITDG Soluciones Prácticas e Ingeniería Sin Fronteras. A continuación se da la tabla con el detalle de las características necesarias para los modelos. Por orden, las columnas indican la potencia nominal, la intensidad nominal, la potencia máxima y el coste:

	PA [W]	IA [A]	PA _{max} [W]	CA [\$]
A1	100	30	300	974,0
A2	500	50	1200	2737,0
A3	1000	50	1750	4105,5
A4	2000	0	3500	5131,9

Tabla A.1 - Características de los 4 tipos de aerogeneradores utilizados

Los costes aquí dados incluyen todo lo necesario para la instalación del aerogenerador salvo el transporte y la mano de obra.

En cada punto de consumo – y por tanto de posible generación – puede instalarse un máximo de 5 aerogeneradores, por cuestiones de espacio.

En relación a las características, las citadas son las necesarias para los modelos implementados. Es necesaria adicionalmente la energía generada en cada punto de consumo para todas y cada una de las comunidades con que se trata en el proyecto a lo largo de las experimentaciones. A continuación se exponen 5 tablas que recogen la energía generada por cada tipo de aerogenerador en cada punto de consumo, para las comunidades de El Alumbre, Alto Perú, Campo Alegre, Alto Perú parte Norte y Alto Perú parte Sur.

Nota: los puntos no tienen asignado ningún nombre dado que ello no es necesario para el proyecto. En su lugar se han asignado números, empezando siempre en cada comunidad por el 1. Como es lógico el usuario X de una comunidad no es el mismo que el usuario X de otra comunidad.



Comunidad de El Alumbre									
	A1	A2	A3	A4		A1	A2	A3	A4
1	423,3	1499,7	3089,8	6130,8	19	502,9	1807,2	3601,8	7194,5
2	629,5	2268,5	4522,6	9047,0	20	671,2	2411,4	4801,2	9618,7
3	799,6	2865,5	5709,3	11454,8	21	745,3	2677,4	5342,1	10709,5
4	568,0	2015,3	4045,0	8068,3	22	549,9	1962,8	3905,7	7813,2
5	707,3	2527,2	5018,3	10043,8	23	611,5	2172,7	4307,3	8616,4
6	859,3	3075,4	6110,9	12261,7	24	256,9	951,6	2004,4	3956,4
7	725,4	2585,1	5128,6	10277,1	25	595,2	2143,7	4294,7	8583,9
8	425,1	1514,2	3126,0	6201,4	26	647,6	2328,2	4669,1	9334,6
9	625,9	2248,6	4477,4	8960,2	27	349,1	1257,3	2610,4	5170,2
10	379,9	1358,6	2822,1	5591,7	28	410,7	1459,9	3006,6	5966,2
11	779,7	2800,4	5627,9	11268,5	29	642,2	2310,1	4625,7	9246,0
12	674,8	2406,0	4768,6	9546,3	30	387,1	1382,1	2861,9	5675,0
13	568,0	2027,9	4055,9	8095,4	31	479,4	1711,4	3437,2	6850,8
14	819,5	2910,7	5776,3	11568,8	32	640,4	2284,8	4544,3	9086,8
15	613,3	2174,5	4296,5	8596,6	33	461,3	1666,1	3328,6	6637,4
16	1125,2	4052,2	8191,3	16464,1	34	65,1	285,8	604,2	1177,7
17	423,3	1499,7	3086,2	6125,4	35	421,5	1494,3	3080,8	6114,5
18	971,5	3487,8	6957,6	13965,8					

Tabla A.2 - Energía generada en los puntos de consumo de la comunidad de El Alumbre (35 beneficiarios)

Comunidad de Alto Perú									
	A1	A2	A3	A4		A1	A2	A3	A4
1	146,5	620,5	1329,6	2596,0	14	341,9	1284,4	2852,9	5589,9
2	338,3	1288,0	2784,1	5468,7	15	325,6	1239,2	2744,3	5374,7
3	186,3	783,3	1736,7	3379,3	16	351,0	1315,2	2903,5	5694,9
4	95,9	445,0	957,0	1857,9	17	392,6	1440,0	3174,9	6239,4
5	238,8	973,3	2167,2	4224,1	18	376,3	1393,0	3064,5	6018,7
6	152,0	662,1	1445,4	2811,2	19	379,9	1400,2	3080,8	6051,2
7	200,8	808,6	1783,7	3484,2	20	408,8	1487,0	3254,5	6402,2
8	94,1	455,9	989,5	1914,0	21	414,3	1497,9	3240,0	6384,1
9	41,6	255,1	519,2	1000,4	22	419,7	1510,5	3268,9	6443,8
10	336,5	1275,4	2831,1	5546,5	23	302,1	1170,4	2605,0	5094,3
11	332,9	1259,1	2796,8	5479,6	24	323,8	1235,6	2737,1	5360,2
12	325,6	1237,4	2749,7	5383,7	25	387,1	1423,7	3144,1	6174,2
13	316,6	1213,9	2700,9	5287,8	26	153,8	642,2	1373,1	2682,8

Tabla A.3 - Energía generada en los puntos de consumo de la comunidad de Alto Perú (26 beneficiarios)



Comunidad de Campo Alegre									
	A1	A2	A3	A4		A1	A2	A3	A4
1	309,3	1087,2	2512,8	4922,4	11	180,9	696,5	1610,0	3147,7
2	392,6	1409,2	3194,8	6284,6	12	199,0	776,1	1776,5	3482,4
3	226,1	879,2	1952,0	3858,7	13	148,3	571,7	1333,3	2596,0
4	182,7	707,3	1620,9	3178,5	14	121,2	483,0	1118,0	2179,9
5	247,8	917,2	2118,4	4144,5	15	142,9	555,4	1266,3	2487,4
6	356,4	1235,6	2834,8	5564,6	16	144,7	557,2	1250,0	2463,9
7	74,2	296,7	687,4	1340,5	17	139,3	522,8	1174,1	2312,0
8	79,6	329,2	772,5	1501,5	18	124,8	492,1	1139,7	2223,3
9	209,8	817,7	1854,3	3645,2	19	124,8	492,1	1139,7	2223,3
10	280,4	1083,6	2465,7	4853,6	20	103,1	410,7	940,7	1839,8

Tabla A.4 - Energía generada en los puntos de consumo de la comunidad de Campo Alegre (20 beneficiarios)

Comunidad de Alto Perú parte Norte									
	A1	A2	A3	A4		A1	A2	A3	A4
1	118,7	310,5	706,8	1525,1	8	85,8	230,1	535,2	1150,7
2	252,1	652,1	1393,6	3095,9	9	89,5	233,8	553,4	1187,2
3	250,2	650,2	1410,0	3103,2	10	73,1	193,6	458,4	975,3
4	259,4	674,0	1450,2	3205,5	11	67,6	180,8	427,4	909,6
5	211,9	553,4	1207,3	2670,3	12	91,3	239,3	557,1	1196,3
6	104,1	275,8	639,3	1380,8	13	98,6	259,4	597,3	1284,0
7	104,1	274,0	633,8	1364,4					

Tabla A.5 - Energía generada en los puntos de consumo de la comunidad de Alto Perú parte Norte (13 beneficiarios)

Comunidad de Alto Perú parte Sur									
	A1	A2	A3	A4		A1	A2	A3	A4
1	142,5	374,4	851,1	1848,4	6	43,8	113,2	263,0	564,4
2	186,3	485,8	1066,7	2343,4	7	47,5	122,4	277,6	599,1
3	74,9	199,1	471,2	1013,7	8	93,2	242,9	557,1	1203,7
4	76,7	204,6	476,7	1017,4	9	255,7	664,8	1413,7	3150,7
5	80,4	210,0	495,0	1052,1					

Tabla A.6 - Energía generada en los puntos de consumo de la comunidad de Alto Perú parte Sur (9 beneficiarios)

Con lo tratado hasta aquí, los aerogeneradores quedan totalmente definidos.

A.2.2. Paneles fotovoltaicos y potencial solar

Se utilizan 4 tipos de paneles fotovoltaicos comerciales, los cuales se pueden adquirir en la capital del país, Lima. A continuación se da la tabla de características de los paneles. Por orden las columnas se refieren al coste, la potencia nominal del panel y la energía generada:



	CS [\$]	PS [W]	ES [W·h/día]
S1	451	50	217,2
S2	636	75	325,7
S3	821	100	434,3
S4	1000	150	651,5

Tabla A.7 – Características de los 4 tipos de paneles fotovoltaicos utilizados

Los costes aquí dados incluyen todo lo necesario para la instalación del panel salvo el transporte y la mano de obra.

En cuanto a la energía generada, a diferencia del caso eólico, se considera el recurso solar constante e uniforme en todos los puntos de consumo, en consecuencia para todos los puntos existe la misma energía generada para un tipo determinado de panel. Para el cálculo de la energía generada que se explica en la memoria del proyecto, se considera un valor de horas solar pico de 4,3 para todas las comunidades y una temperatura media de 8°C también para todas las comunidades. El rendimiento así obtenido para los paneles fotovoltaicos es de 1,01.

Se considera que por cuestiones de espacio en cada punto se pueden instalar un máximo de 10 paneles fotovoltaicos.

A.3. Componentes generales de los sistemas de electrificación

En este capítulo se describen aquellos componentes que se incluyen en todos los sistemas de electrificación rural con que se trabaja a lo largo del proyecto.

A.3.1. Reguladores eólicos

Se utilizan 4 tipos de reguladores eólicos y en cada punto se puede situar un máximo de 5 reguladores¹. A continuación se expone la tabla con las características. Por orden, las columnas se refieren al coste y la potencia nominal:

	CR [\$]	PR [W]
RA1	165	420
RA2	285	1440
RA3	342	1800
RA4	513	3600

Tabla A.8 - Características de los 4 tipos de reguladores eólicos

¹ Las limitaciones en el número de componentes para los componentes generales no tienen que ver con una cuestión de espacio, sino con un tema de limitar y acotar las posibilidades que se dan al modelo, de forma que los tiempos de cálculo se reduzcan sin que ello suponga un obstáculo a la solución.



Tal y como se puede ver, la potencia de los reguladores eólicos queda ligeramente sobredimensionada respecto a la potencia máxima de los aerogeneradores, de modo que cada regulador acepta a un aerogenerador.

A.3.2. Reguladores solares

Se utilizan 4 tipos de reguladores solares y en cada punto se puede situar un máximo de 10 reguladores. A continuación se expone la tabla de características. Por orden, las columnas se refieren al coste y la potencia nominal:

	CRs [€]	PRs [W]
RS1	67	50
RS2	81	75
RS3	95	100
RS4	125	200

Tabla A.9 - Características de los 4 tipos de reguladores solares

Tal y como se puede ver, la potencia de los reguladores solares queda adecuada respecto a la potencia máxima de los paneles fotovoltaicos, de modo que cada regulador acepta a un panel.

A.3.3. Baterías

Existen 4 tipos de baterías y en cada punto se puede situar un máximo de 3 baterías. A continuación se expone la tabla de características. Por orden, las columnas se refieren al coste y la energía almacenada en las baterías:

	CB [€]	EB [W-h/día]
B1	225	1500
B2	246	1800
B3	292	2400
B4	325	3000

Tabla A.10 - Características de los 4 tipos de baterías

El rendimiento energético de todas las baterías es del 85%. No se considera rendimiento de potencia.

A.3.4. Inversores

Existen 4 tipos de inversores y en cada punto se puede situar un máximo de 2 inversores. A continuación se expone la tabla de características. Por orden, las columnas se refieren al coste y la potencia máxima admisible:



	CI [€]	PI [W]
B1	377	300
B2	1200	1200
B3	1800	2000
B4	2300	3000

Tabla A.11 - Características de los 4 tipos de inversores

El rendimiento energético de todos los inversores es del 85%. No se considera rendimiento de potencia.

A.3.5. Medidores

Existe un único tipo de medidor, cuyo coste es de 50€.

A.3.6. Conductores

El cálculo de los conductores es posiblemente el más complejo de todos los componentes. En primer lugar, existen 3 tipos de conductores, las características de los cuales se detallan en la tabla siguiente. Por orden, las columnas se refieren al coste, la resistividad y la intensidad máxima admisible:

	CC	RCo	IC
C1	4,9	0,00271	89
C2	5,1	0,00215	101
C3	5,25	0,00171	118

Tabla A.12 - Características de los 3 tipos de conductores

Para el cálculo de los costes, se han tenido en cuenta:

- 1 poste cada 50 metros. A ello se debe añadir el poste de final de micro red, no incluido aquí sino en los distintos modelos². Los postes tiene un espesor de 80x120 m.
- 1 perno gancho por poste.
- 0,5 grampas por poste.
- 1,5 empalmes (conector + tapa) por poste.
- 10m de acometidas por poste.
- 0,33 retenidas por poste.

Con esto se calcula el coste del poste y a sabiendas de que hay 1 por cada 50m, se puede calcular el coste de los componentes adicionales por metro. A este coste, se le suma el cose por metro de cada uno de los 3 tipos de conductores, obteniéndose así los costes de la tabal 12.

Con la inclusión de los distintos componentes adicionales sumados al precio de los conductores, se tiene el coste por metro de micro red.

² Véase restricción (20) del “modelo de partida”, apartado 3.3.2.





B. Combinación de modelos

En este anexo, se da el detalle de las variables, función objetivo y restricciones tenidas en cuenta en cada una de las 14 posibles combinaciones que se utilizan en el capítulo 5 de la memoria para la experimentación. Dado que no se trata aquí de dar una gran explicación sino únicamente presentar todo lo que incluye cada modelo, se obvian a lo largo del anexo las explicaciones de variables y restricciones, limitándose únicamente a su exposición.

B.1. 01 – Libre

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.

Función objetivo

$$\begin{aligned}
 [MIN] Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$



Restricciones

$$\sum_{a=1}^A x a_{da} \leq N A \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S x s_{ds} \leq N S \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A x a_{da} + \sum_{s=1}^S x s_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f e_{dq} \quad d = 1, \dots, D \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D f p_{pd} + \sum_{i=1}^I P I_i \cdot x i_{di} \geq F S \cdot P D_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f p_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B E B_b \cdot x b_{db} + \left(\frac{V B}{D B} \sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{V B}{D B} \left(\sum_{q \in Q_d} f e_{dq} + E D_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{s=1}^S E S_s \cdot x s_{ds} \geq S O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq E O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{P D_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot R C_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min}) (1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$



$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{\min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

B.2. 02 – Máximo 1 micro red

Variables

- $xa_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $xb_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $xi_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $xr_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $xc_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$
- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$
- $v_d; v_d \in [V_{\min}, V_{\max}]; d = 1, \dots, D.$
- $xm_d; d = 1, \dots, D.$
- $xs_{ds}; p = 1, \dots, D; s = 1, \dots, S.$
- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$
- $nmr_d; d = 1, \dots, D.$



Función objetivo

$$\begin{aligned}
[MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
& \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
\end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \tag{5}$$

$$\frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \tag{6}$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \tag{7}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq \tag{8}$$

$$SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \tag{9}$$

$$EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \tag{10}$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \tag{11}$$



$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta_c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24)$$

B.3. 03 – Mínimo 25% por micro red

Variables

- $xa_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $xb_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $xi_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $xr_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $xc_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$
- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$



- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.
- nmr_d ; $d = 1, \dots, D$.
- xf_{pdf} ; $p = 1, \dots, D$; $d \in Q_p$; $f = 1, \dots, D$.

Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \tag{5}$$

$$\frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \tag{6}$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \tag{7}$$



$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq$$

$$SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq$$

$$EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p=1, \dots, D; d \in Q_p \quad (10)$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p=1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d=1, \dots, D; i=1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$



$$fe_{pd} \geq \sum_{f=1}^D x_{pdf}^f \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p = 1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D x_{pdd}^f + x_d \geq 1 \quad d = 1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D x_{pdf}^f + x_d \geq \sum_{q \in Q_d} x_{dqf}^f \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D x_{pdf}^f \leq \sum_{q \in Q_d} x_{dqf}^f \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D x_{dqf}^f \geq nmr_d (U_{min} - 1) \quad d = 1, \dots, D \quad (29)$$

B.4. 04 – Máximo 1 micro red de mínimo 25%

Variables

- $xa_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $xb_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $xi_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $xr_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $xc_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$
- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$
- $v_d; v_d \in [V_{min}, V_{max}]; d = 1, \dots, D.$
- $xm_d; d = 1, \dots, D.$
- $xs_{ds}; p = 1, \dots, D; s = 1, \dots, S.$
- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$
- $nmr_d; d = 1, \dots, D.$
- $x_{pdf}^f; p = 1, \dots, D; d \in Q_p; f = 1, \dots, D.$



Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \quad (1)$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D
 \end{aligned} \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq \\
 SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D
 \end{aligned} \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \quad (9)$$

$$EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$



$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p=1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d=1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d=1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d=1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d=1, \dots, D; i=1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d=1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d=1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d=1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d=1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d=1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24b)$$

$$fe_{pd} \geq \sum_{j=1}^D xf_{pdf} \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p=1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdd} + x_d \geq 1 \quad d=1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} + x_d \geq \sum_{q \in Q_d} xf_{dqf} \quad d=1, \dots, D; f=1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} \leq \sum_{q \in Q_d} xf_{pdf} \quad d=1, \dots, D; f=1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D xf_{dqf} \geq nmr_d (U_{min} - 1) \quad d=1, \dots, D \quad (29)$$



B.5. 05 – Máximo 25% independientes

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.

Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \tag{5}$$

$$\frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D$$



$$\sum_{p=1|d \in Q_p}^D f p_{pd} + \sum_{i=1}^I P I_i \cdot x i_{di} \geq F S \cdot P D_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f p_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B E B_b \cdot x b_{db} + \left(\frac{V B}{D B} \sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{V B}{D B} \left(\sum_{q \in Q_d} f e_{dq} + E D_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{s=1}^S E S_s \cdot x s_{ds} \geq$$

$$S O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq$$

$$E O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{P D_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot R C_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min}) (1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{f p_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{P D_j}{V_{min} \cdot \eta c} \right) (1 - x c_{pdc}) \leq I C_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R P R_r \cdot x r_{dr} \geq \sum_{a=1}^A P A_a \cdot x a_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z P Z_z \cdot x r s_{dz} \geq \sum_{s=1}^S P S_s \cdot x s_{ds} \quad d = 1, \dots, D \quad (16)$$

$$x i_{di} \leq N I \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C x c_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} \leq (D-1) x m_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C x c_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} \geq x m_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} x c_{dq} \geq 1 - x f r_d \quad d = 1, \dots, D \quad (20)$$



$$\sum_{d=1}^D xmr_d \geq D - U_{indep} \quad (21)$$

B.6. 06 – Máximo 1 micro red y 25% independientes

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.
- nmr_d ; $d = 1, \dots, D$.

Función objetivo

$$[MIN] Z = \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d \quad (1)$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \quad (3)$$



$$E_{min} \cdot z_d \leq \sum_{a=1}^A x a_{da} + \sum_{s=1}^S x s_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f e_{dq} \quad d = 1, \dots, D \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D f p_{pd} + \sum_{i=1}^I P I_i \cdot x i_{di} \geq F S \cdot P D_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f p_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B E B_b \cdot x b_{db} + \left(\frac{V B}{D B} \sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{V B}{D B} \left(\sum_{q \in Q_d} f e_{dq} + E D_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{s=1}^S E S_s \cdot x s_{ds} \geq S O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq E O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{P D_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot R C_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min}) (1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{f p_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{P D_j}{V_{min} \cdot \eta c} \right) (1 - x c_{pdc}) \leq I C_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R P R_r \cdot x r_{dr} \geq \sum_{a=1}^A P A_a \cdot x a_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z P Z_z \cdot x r s_{dz} \geq \sum_{s=1}^S P S_s \cdot x s_{ds} \quad d = 1, \dots, D \quad (16)$$

$$x i_{di} \leq N I \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$



$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$\sum_{d=1}^D xmr_d \geq D - U_{indep} \quad (21)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24)$$

B.7. 07 – Mínimo 25% por micro red y máximo 25% independientes (07)

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.
- nmr_d ; $d = 1, \dots, D$.
- xf_{pdf} ; $p = 1, \dots, D$; $d \in Q_p$; $f = 1, \dots, D$.



Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + \sum_{d=1}^D CM \cdot xm_d + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq$$

$$\frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \tag{6}$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \tag{7}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq$$

$$SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq$$

$$EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \tag{10}$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \tag{11}$$



$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta_c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$\sum_{d=1}^D xmr_d \geq D - U_{indep} \quad (21)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$fe_{pd} \geq \sum_{f=1}^D xf_{pdf} \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p = 1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdd} + x_d \geq 1 \quad d = 1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} + x_d \geq \sum_{q \in Q_d} xf_{dqf} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} \leq \sum_{q \in Q_d} xf_{pdq} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D xf_{dqf} \geq nmr_d (U_{min} - 1) \quad d = 1, \dots, D \quad (29)$$



B.8. 09 – Libre y todos medidor**Variables**

- $xa_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $xb_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $xi_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $xr_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $xc_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$
- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$
- $v_d; v_d \in [V_{min}, V_{max}]; d = 1, \dots, D.$
- $xs_{ds}; p = 1, \dots, D; s = 1, \dots, S.$
- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$

Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D \tag{5}$$



$$\sum_{p=1|d \in Q_p}^D f p_{pd} + \sum_{i=1}^I P I_i \cdot x i_{di} \geq F S \cdot P D_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f p_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B E B_b \cdot x b_{db} + \left(\frac{V B}{D B} \sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{V B}{D B} \left(\sum_{q \in Q_d} f e_{dq} + E D_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{s=1}^S E S_s \cdot x s_{ds} \geq S O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq E O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{P D_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot R C_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min}) (1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{f p_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{P D_j}{V_{min} \cdot \eta c} \right) (1 - x c_{pdc}) \leq I C_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R P R_r \cdot x r_{dr} \geq \sum_{a=1}^A P A_a \cdot x a_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z P Z_z \cdot x r s_{dz} \geq \sum_{s=1}^S P S_s \cdot x s_{ds} \quad d = 1, \dots, D \quad (16)$$

$$x i_{di} \leq N I \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$z_d + \sum_{q \in Q_d} x c_{dq} \geq 1 - x f r_d \quad d = 1, \dots, D \quad (20)$$



B.9. 10 – Máximo 1 micro red y todos medidor

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.
- nmr_d ; $d = 1, \dots, D$.

Función objetivo

$$\begin{aligned}
 [MIN] Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$



$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$



$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d=1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d=1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d=1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d=1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24)$$

B.10. 11 – Mínimo 25% por micro red y todos medidor

Variables

- xa_{da} ; $d=1, \dots, D$; $a=1, \dots, A$.
- xb_{db} ; $d=1, \dots, D$; $b=1, \dots, B$.
- xi_{di} ; $d=1, \dots, D$; $i=1, \dots, I$.
- xr_{dr} ; $d=1, \dots, D$; $r=1, \dots, R$.
- xc_{pdc} ; $p=1, \dots, D$; $d \in Q_p$; $c=1, \dots, C$.
- fe_{pd} ; $p=1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p=1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d=1, \dots, D$.
- xm_d ; $d=1, \dots, D$.
- xs_{ds} ; $p=1, \dots, D$; $s=1, \dots, S$.
- xrs_{dz} ; $d=1, \dots, D$; $z=1, \dots, Z$.
- z_d ; $d=1, \dots, D$.
- xfr_d ; $d=1, \dots, D$.
- nmr_d ; $d=1, \dots, D$.
- xf_{pdf} ; $p=1, \dots, D$; $d \in Q_p$; $f=1, \dots, D$.



Función objetivo

$$\begin{aligned}
 [MIN] Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \quad (1)$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D
 \end{aligned} \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq \\
 SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D
 \end{aligned} \quad (8)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D
 \end{aligned} \quad (9)$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$



$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta_c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xr_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$fe_{pd} \geq \sum_{f=1}^D xf_{pdf} \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p = 1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdd} + x_d \geq 1 \quad d = 1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} + x_d \geq \sum_{q \in Q_d} xf_{dqf} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} \leq \sum_{q \in Q_d} xf_{pdf} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D xf_{dqf} \geq nmr_d (U_{min} - 1) \quad d = 1, \dots, D \quad (29)$$



B.11. 12 – Máximo 1 micro red de mínimo 25% y todos medidor

Variables

- xa_{da} ; $d = 1, \dots, D$; $a = 1, \dots, A$.
- xb_{db} ; $d = 1, \dots, D$; $b = 1, \dots, B$.
- xi_{di} ; $d = 1, \dots, D$; $i = 1, \dots, I$.
- xr_{dr} ; $d = 1, \dots, D$; $r = 1, \dots, R$.
- xc_{pdc} ; $p = 1, \dots, D$; $d \in Q_p$; $c = 1, \dots, C$.
- fe_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p = 1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d = 1, \dots, D$.
- xm_d ; $d = 1, \dots, D$.
- xs_{ds} ; $p = 1, \dots, D$; $s = 1, \dots, S$.
- xrs_{dz} ; $d = 1, \dots, D$; $z = 1, \dots, Z$.
- z_d ; $d = 1, \dots, D$.
- xfr_d ; $d = 1, \dots, D$.
- nmr_d ; $d = 1, \dots, D$.
- xf_{pdf} ; $p = 1, \dots, D$; $d \in Q_p$; $f = 1, \dots, D$.

Función objetivo

$$\begin{aligned}
 [MIN] Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \tag{1}$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \tag{2}$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \tag{3}$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \tag{4}$$



$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$



$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d=1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d=1, \dots, D \quad (20)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d=1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d=1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24b)$$

$$fe_{pd} \geq \sum_{f=1}^D xf_{pdf} \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p=1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdd} + x_d \geq 1 \quad d=1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} + x_d \geq \sum_{q \in Q_d} xf_{dqf} \quad d=1, \dots, D; f=1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} \leq \sum_{q \in Q_d} xf_{pdf} \quad d=1, \dots, D; f=1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D xf_{dqf} \geq nmr_d (U_{min} - 1) \quad d=1, \dots, D \quad (29)$$

B.12. 13 – Máximo 25% independientes y todos medidor

Variables

- xa_{da} ; $d=1, \dots, D$; $a=1, \dots, A$.
- xb_{db} ; $d=1, \dots, D$; $b=1, \dots, B$.
- xi_{di} ; $d=1, \dots, D$; $i=1, \dots, I$.
- xr_{dr} ; $d=1, \dots, D$; $r=1, \dots, R$.
- xc_{pdc} ; $p=1, \dots, D$; $d \in Q_p$; $c=1, \dots, C$.
- fe_{pd} ; $p=1, \dots, D$; $d \in Q_p$.
- fp_{pd} ; $p=1, \dots, D$; $d \in Q_p$.
- v_d ; $v_d \in [V_{min}, V_{max}]$; $d=1, \dots, D$.
- xm_d ; $d=1, \dots, D$.
- xs_{ds} ; $p=1, \dots, D$; $s=1, \dots, S$.



- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$

Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \quad (1)$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D
 \end{aligned} \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq \\
 SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D
 \end{aligned} \quad (8)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D
 \end{aligned} \quad (9)$$



$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min})(1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$

$$\frac{f p_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - x c_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R P R_r \cdot x r_{dr} \geq \sum_{a=1}^A P A_a \cdot x a_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z P Z_z \cdot x r s_{dz} \geq \sum_{s=1}^S P S_s \cdot x s_{ds} \quad d = 1, \dots, D \quad (16)$$

$$x i_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C x c_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} \leq (D-1) x m_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C x c_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} \geq x m_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} x c_{dq} \geq 1 - x f r_d \quad d = 1, \dots, D \quad (20)$$

$$\sum_{d=1}^D x m r_d \geq D - U_{indep} \quad (21)$$

B.13. 14 – Máximo 1 micro red y 25% independientes y todos medidor

Variables

- $x a_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $x b_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $x i_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $x r_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $x c_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$



- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$
- $v_d; v_d \in [V_{min}, V_{max}]; d = 1, \dots, D.$
- $xm_d; d = 1, \dots, D.$
- $xs_{ds}; p = 1, \dots, D; s = 1, \dots, S.$
- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$
- $nmr_d; d = 1, \dots, D.$

Función objetivo

$$\begin{aligned}
 [MIN]Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \quad (1)$$

Restricciones

$$\sum_{a=1}^A xa_{da} \leq NA \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S xs_{ds} \leq NS \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A xa_{da} + \sum_{s=1}^S xs_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\begin{aligned}
 \sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq \\
 \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fe_{dq} \quad d = 1, \dots, D
 \end{aligned} \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D fp_{pd} + \sum_{i=1}^I PI_i \cdot xi_{di} \geq FS \cdot PD_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} fp_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B EB_b \cdot xb_{db} + \left(\frac{VB}{DB} \sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{VB}{DB} \left(\sum_{q \in Q_d} fe_{dq} + ED_d \right) \quad d = 1, \dots, D \quad (7)$$



$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{s=1}^S ES_s \cdot xs_{ds} \geq$$

$$SOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D fe_{pd} + \sum_{a=1}^A EA_{da} \cdot xa_{da} \geq$$

$$EOL \cdot \left(\sum_{q \in Q_d} fe_{dq} + \frac{ED_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$fe_{pd} \leq \left(\sum_{j=1}^D \frac{ED_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p=1, \dots, D; d \in Q_p \quad (10)$$

$$fp_{pd} \leq \left(\sum_{j=1}^D \frac{PD_j}{\eta c} \right) \sum_{c=1}^C xc_{pdc} \quad p=1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot RC_c \cdot fp_{pd}}{V_n} - (V_{max} - V_{min})(1 - xc_{pdc}) \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (13)$$

$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{min} \cdot \eta c} \right) (1 - xc_{pdc}) \leq IC_c \quad p=1, \dots, D; d \in Q_p; c=1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d=1, \dots, D; i=1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$\sum_{d=1}^D xmr_d \geq D - U_{indep} \quad (21)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$



$$2 - z_d - xm_d \leq \frac{Q}{2}(1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$\sum_{d=1}^D nmr_d \leq N_{max} \quad (24)$$

B.14. 15 – Mínimo 25% por micro red y máximo 25% independientes y todos medidor

Variables

- $xa_{da}; d = 1, \dots, D; a = 1, \dots, A.$
- $xb_{db}; d = 1, \dots, D; b = 1, \dots, B.$
- $xi_{di}; d = 1, \dots, D; i = 1, \dots, I.$
- $xr_{dr}; d = 1, \dots, D; r = 1, \dots, R.$
- $xc_{pdc}; p = 1, \dots, D; d \in Q_p; c = 1, \dots, C.$
- $fe_{pd}; p = 1, \dots, D; d \in Q_p.$
- $fp_{pd}; p = 1, \dots, D; d \in Q_p.$
- $v_d; v_d \in [V_{min}, V_{max}]; d = 1, \dots, D.$
- $xm_d; d = 1, \dots, D.$
- $xs_{ds}; p = 1, \dots, D; s = 1, \dots, S.$
- $xrs_{dz}; d = 1, \dots, D; z = 1, \dots, Z.$
- $z_d; d = 1, \dots, D.$
- $xfr_d; d = 1, \dots, D.$
- $nmr_d; d = 1, \dots, D.$
- $xf_{pdf}; p = 1, \dots, D; d \in Q_p; f = 1, \dots, D.$

Función objetivo

$$\begin{aligned}
 [MIN] Z = & \sum_{d=1}^D \sum_{a=1}^A CA_a \cdot xa_{da} + \sum_{p=1}^D \sum_{d \in Q_p} \sum_{c=1}^C L_{pd} \cdot CC_c \cdot xc_{pdc} + \sum_{d=1}^D \sum_{b=1}^B CB_b \cdot xb_{db} + \sum_{d=1}^D \sum_{i=1}^I CI_i \cdot xi_{di} + \\
 & \sum_{d=1}^D \sum_{r=1}^R CR_r \cdot xr_{dr} + CM \cdot Q + \sum_{d=1}^D \sum_{s=1}^S CS_s \cdot xs_{ds} + \sum_{d=1}^D \sum_{z=1}^Z CZ_z \cdot xrs_{dz} + \sum_{d=1}^D C_{poste} \cdot xfr_d
 \end{aligned} \quad (1)$$



Restricciones

$$\sum_{a=1}^A x a_{da} \leq N A \cdot z_d \quad d = 1, \dots, D \quad (2)$$

$$\sum_{s=1}^S x s_{ds} \leq N S \cdot z_d \quad d = 1, \dots, D \quad (3)$$

$$E_{min} \cdot z_d \leq \sum_{a=1}^A x a_{da} + \sum_{s=1}^S x s_{ds} \quad d = 1, \dots, D \quad (4)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f e_{dq} \quad d = 1, \dots, D \quad (5)$$

$$\sum_{p=1|d \in Q_p}^D f p_{pd} + \sum_{i=1}^I P I_i \cdot x i_{di} \geq F S \cdot P D_d \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) + \sum_{q \in Q_d} f p_{dq} \quad d = 1, \dots, D \quad (6)$$

$$\sum_{b=1}^B E B_b \cdot x b_{db} + \left(\frac{V B}{D B} \sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) (1 - x_d) \geq \frac{V B}{D B} \left(\sum_{q \in Q_d} f e_{dq} + E D_d \right) \quad d = 1, \dots, D \quad (7)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{s=1}^S E S_s \cdot x s_{ds} \geq S O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (8)$$

$$\sum_{p=1|d \in Q_p}^D f e_{pd} + \sum_{a=1}^A E A_{da} \cdot x a_{da} \geq E O L \cdot \left(\sum_{q \in Q_d} f e_{dq} + \frac{E D_d}{\eta b \cdot \eta i} \left(\frac{1}{\eta c} + \left(1 - \frac{1}{\eta c} \right) z_d \right) \right) \quad d = 1, \dots, D \quad (9)$$

$$f e_{pd} \leq \left(\sum_{j=1}^D \frac{E D_j}{\eta b \cdot \eta i \cdot \eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (10)$$

$$f p_{pd} \leq \left(\sum_{j=1}^D \frac{P D_j}{\eta c} \right) \sum_{c=1}^C x c_{pdc} \quad p = 1, \dots, D; d \in Q_p \quad (11)$$

$$\sum_{p=1|d \in Q_p}^D \sum_{c=1}^C x c_{pdc} + x_d \leq 1 \quad d = 1, \dots, D \quad (12)$$

$$v_p - v_d \geq \frac{L_{pd} \cdot R C_c \cdot f p_{pd}}{V_n} - (V_{max} - V_{min}) (1 - x c_{pdc}) \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (13)$$



$$\frac{fp_{pd}}{V_n} - \left(\sum_{j=1}^D \frac{PD_j}{V_{\min} \cdot \eta_c} \right) (1 - xc_{pdc}) \leq IC_c \quad p = 1, \dots, D; d \in Q_p; c = 1, \dots, C \quad (14)$$

$$\sum_{r=1}^R PR_r \cdot xr_{dr} \geq \sum_{a=1}^A PA_a \cdot xa_{da} \quad d = 1, \dots, D \quad (15)$$

$$\sum_{z=1}^Z PZ_z \cdot xrs_{dz} \geq \sum_{s=1}^S PS_s \cdot xs_{ds} \quad d = 1, \dots, D \quad (16)$$

$$xi_{di} \leq NI \cdot z_d \quad d = 1, \dots, D; i = 1, \dots, I \quad (17)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \leq (D-1) xm_d \quad d = 1, \dots, D \quad (18)$$

$$\sum_{q \in Q_d} \sum_{c=1}^C xc_{dq} + \sum_{p=1|d \in Q_p}^D \sum_{c=1}^C xc_{pdc} \geq xm_d \quad d = 1, \dots, D \quad (19)$$

$$z_d + \sum_{q \in Q_d} xc_{dq} \geq 1 - xfr_d \quad d = 1, \dots, D \quad (20)$$

$$\sum_{d=1}^D xmr_d \geq D - U_{\text{indep}} \quad (21)$$

$$2 - z_p - xm_d \geq 1 - nmr_d \quad d = 1, \dots, D \quad (22)$$

$$2 - z_d - xm_d \leq \frac{Q}{2} (1 - nmr_d) \quad d = 1, \dots, D \quad (23)$$

$$fe_{pd} \geq \sum_{f=1}^D xf_{pdf} \cdot \frac{ED}{\eta_c \cdot \eta_i \cdot \eta_b} \quad p = 1, \dots, D; d \in Q_p \quad (25)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdd} + x_d \geq 1 \quad d = 1, \dots, D \quad (26)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} + x_d \geq \sum_{q \in Q_d} xf_{dqf} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (27)$$

$$\sum_{p=1|d \in Q_p}^D xf_{pdf} \leq \sum_{q \in Q_d} xf_{pdf} \quad d = 1, \dots, D; f = 1, \dots, D | d \neq f \quad (28)$$

$$\sum_{q \in Q_d} \sum_{f=1}^D xf_{dqf} \geq nmr_d (U_{\min} - 1) \quad d = 1, \dots, D \quad (29)$$

