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Physical adequacy in power generation: Spain beyond 2020

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Introduction

- Unmet demand for electricity: economic and social costs.
- Concerns: reliability, safety, security of electricity supply (SoS).
- SoS is a broad concept: power supply is a complex chain.
- A common idea: avoid adverse events that give rise to interruptions.

- Supply is exposed to unexpected events:
  - Uncertainty (no quantitative estimates): scenario analyses
  - Risk (quantitative estimates): risk metrics

Introduction

- A key ingredient to SoS: system adequacy. EC(2016):
  - Power generation
  - Power demand
  - Availability of lines

  → Adequacy metrics

- We develop a stochastic model; we demonstrate it by example:
  - *quantity based: physical adequacy*
  - *peak demand = f(annual demand)*
  - *Spain: an “electric island”*

  → *MC: risk profile*

Introduction

- We account for both:
  - Uncertainties (scenarios):
    - Spanish METI (2015): demand growth of 1.9% (in [1.7%; 2.3%])
    - Bailera & Lisbona (2018):
      - demand growth of 1.36% (D_1), generation park (S_1)
      - demand growth of 1.73% (D_2), generation park (S_2)
  - Risks (metrics): power demand, power supply (thermal, non-thermal)
- Adequacy metrics: RM, EENS, E95, LOLE, L95, LOLP
- Our base case: (S_1,D_1), (S_2, D_2)
  - Flat demand: (S_1,D), (S_2, D)
  - 5% cut in demand: (S_1,D^-_1), (S_2, D^-_2); (S_1,D^-), (S_2, D^-)
  - 5% cut in demand & more gas plants: (S^+_1,D^-_1), (S^+_2, D^-_2)
- System's adequacy worsens in 2020, dramatically in 2040 and 2050.

A stochastic model

- Hourly peak demand in a year ***t*** as a function of the yearly demand in ***t***:

$$\ln\tilde{q} = \alpha + \beta \times \ln\tilde{Q} + \tilde{e}.$$

- Power supply:
  - Thermal (***j*** = ***c***, ***g***, ***n***): random availability rate

$$A_j^i = \left\{ \begin{array}{l} 0,\ \text{'off' state with probability } 1 - \Lambda_j^i \\ 1,\ \text{'on' state with probability } \Lambda_j^i \end{array} \right\}$$

  - Non-thermal (hydro, wind, solar, cogeneration, others): random load factor

$$f(x) = \left\{ \begin{array}{l} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} \ \text{if } x \geq 0 \\ 0 \ \text{if } x < 0 \end{array} \right\}$$

A stochastic model

- Physical adequacy metrics:
  - *Deterministic*:

RM: Reserve margin = (available generation capacity / maximum annual load) - 1

  - *Probabilistic*:

EENS (MWh): Expected energy not supplied = unmet electricity demand in year ***t***

E95 (MWh): 95-th percentile of EENS

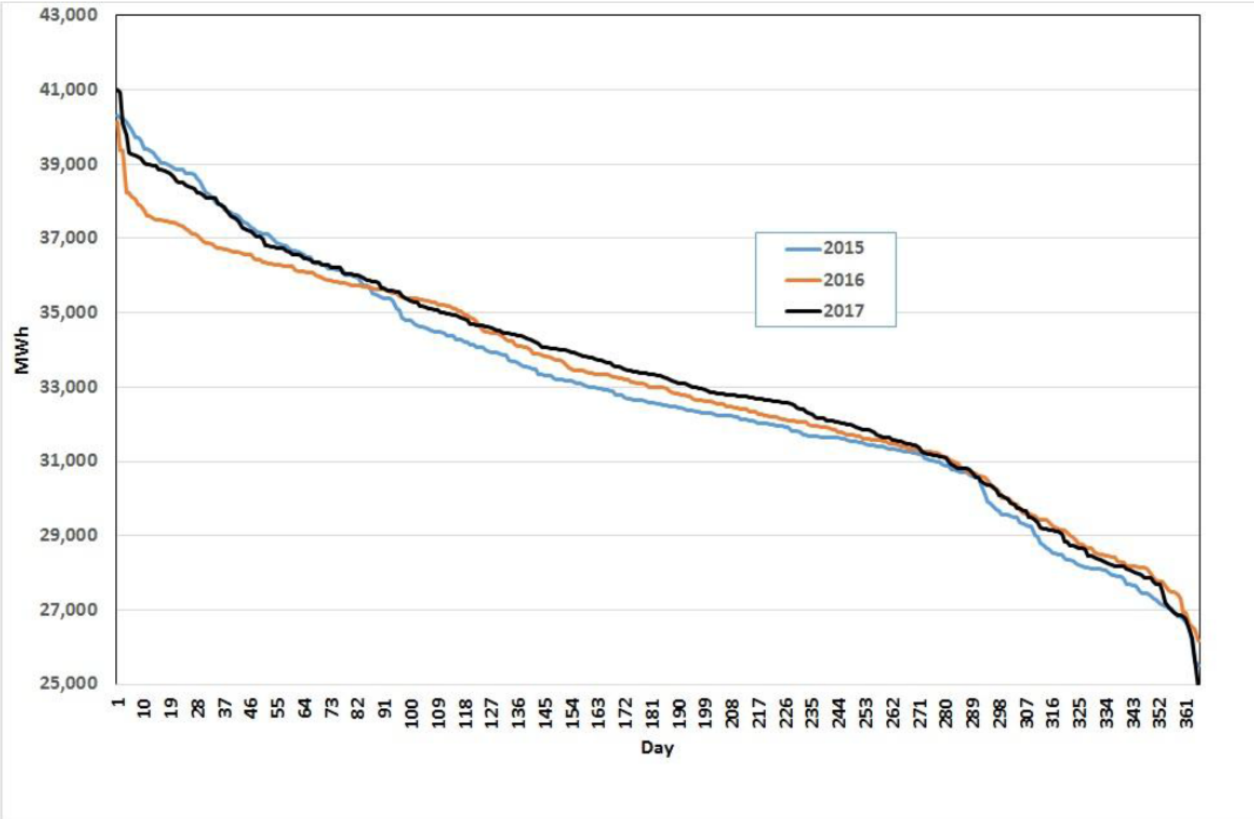
LOLE (hours): Loss of load expectation = average number of hours with EENS occurrence

L95 (hours): 95-th percentile of LOLE

LOLP: Loss of load probability = probability that annual peak load will exceed available generation

A heuristic application in Spain: Demand

- Mainland (peninsular) system with a long-term perspective (2017-2050).
- Hourly peak demand on a daily basis: since 2015.



A heuristic application in Spain : Demand

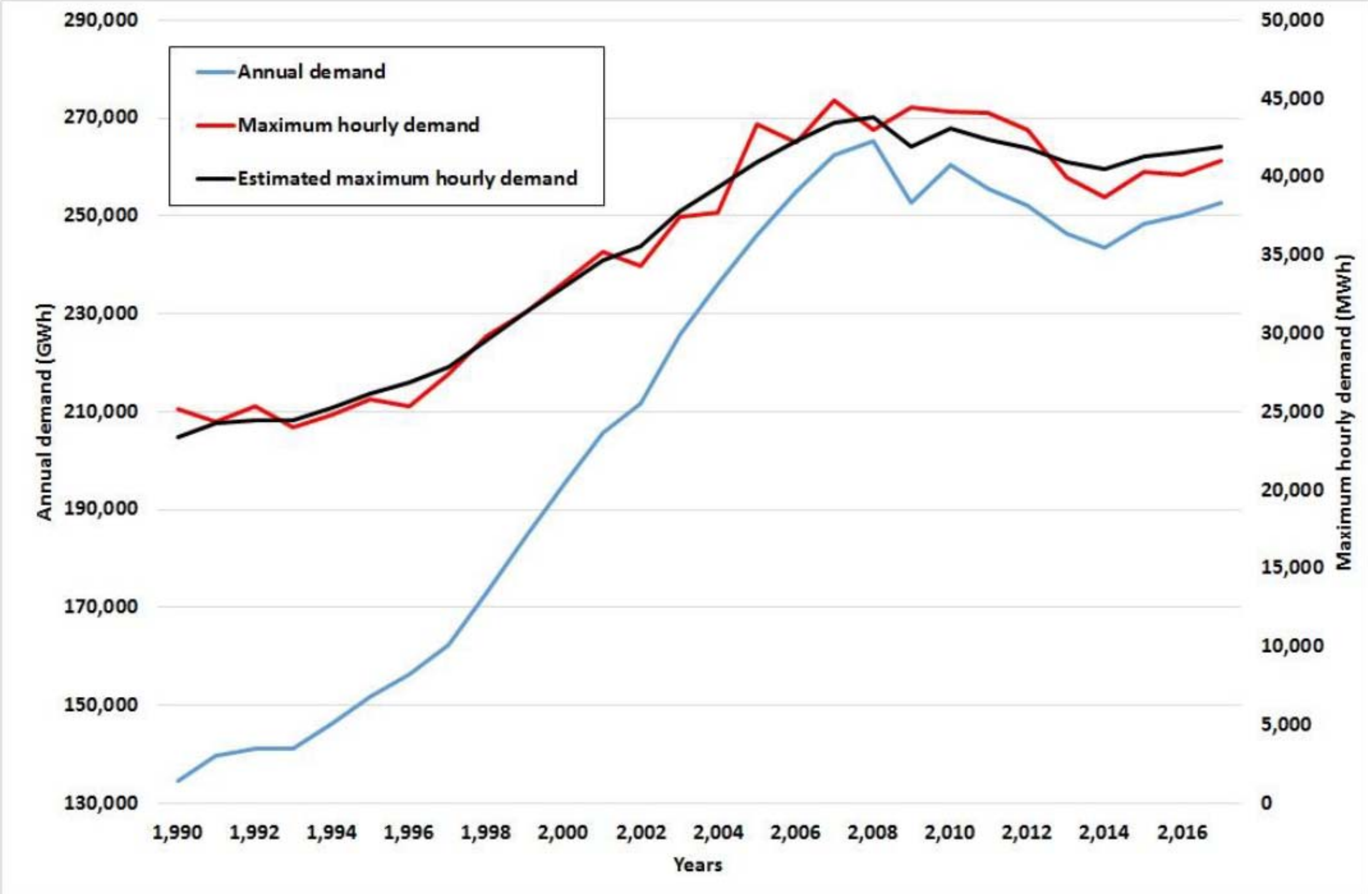
- Hourly peak demand and yearly demand on an annual basis: since 1990.

α = -7.24270
(-10.82)

β = 0.924459
(26.45)

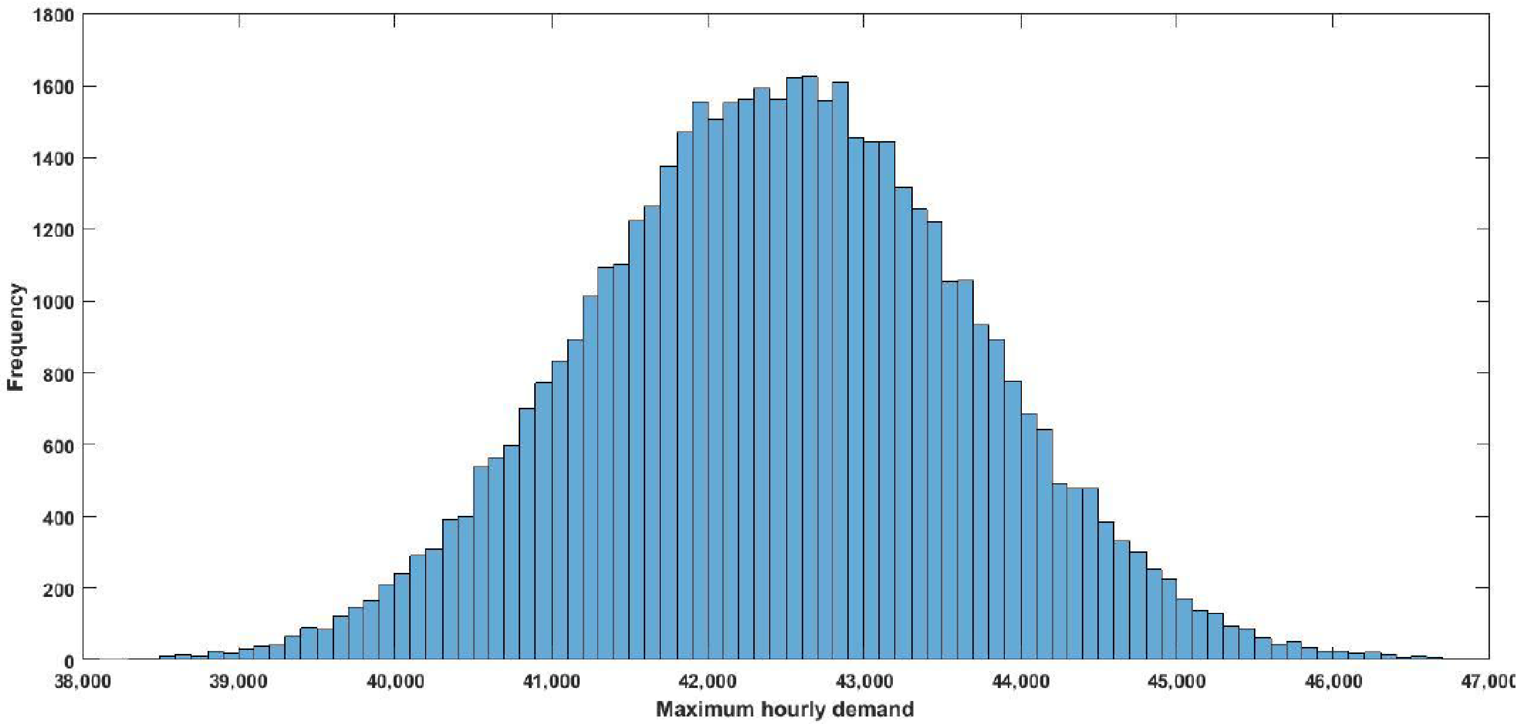
aR^2 = 0.976980

s.e. 0.034453



A heuristic application in Spain : Demand

- 2017 Actual hourly peak demand: 41,683 MWh
- 2017 Regression-based hourly peak demand: 42,386 MWh
- 2017 Simulation-based (average) hourly peak demand: 42,398 MWh



A heuristic application in Spain : Demand

- We can apply the same procedure in any future year:
  - Start from demand level in 2017
  - Assume a particular growth rate
  - Set the number of years ahead
  - Get the forecast of total demand in that year
  - Compute the expected hourly peak demand in that year

- We can simulate the hourly peak demand on a daily basis in that year:
  - Take a single simulation run
  - Observe the hourly peak demand in it
  - Calculate the difference with respect to the one in 2017
  - Displace the whole load curve in 2017 by that amount

A heuristic application in Spain: Supply

Table 1. Peninsular Spanish power system (in MW, except demand D in bottom row).									
		Demand growth: +1.36%				Demand growth: +1.73%			
	2017	*2020*	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Nuclear	7,117	7,117	3,040	0	0	7,117	3,040	0	0
Coal	9,536	9,536	6,642	0	0	9,536	6,642	0	0
Nat.Gas	24,948	24,948	24,948	24,948	24,948	24,948	24,948	24,948	24,948
Hydro	20,331	20,331	21,900	24,700	25,600	20,331	23,300	25,900	28,600
Wind	22,863	26,000	28,700	32,100	35,800	24,500	32,600	39,800	44,400
Solar	6,730	16,000	20,500	24,600	29,400	15,100	20,300	27,300	39,300
Cogen.	6,373	8,100	9,900	10,800	11,600	8,100	10,800	13,200	16,100
Others	1,413	1,200	2,800	3,800	5,300	1,200	2,000	3,500	6,200
Total(MW)	99,311	113,232	118,430	120,948	132,648	110,832	123,630	134,648	159,548
D(GWh)	253,082	263,621	302,026	346,026	396,436	266,564	316,909	376,762	447,920

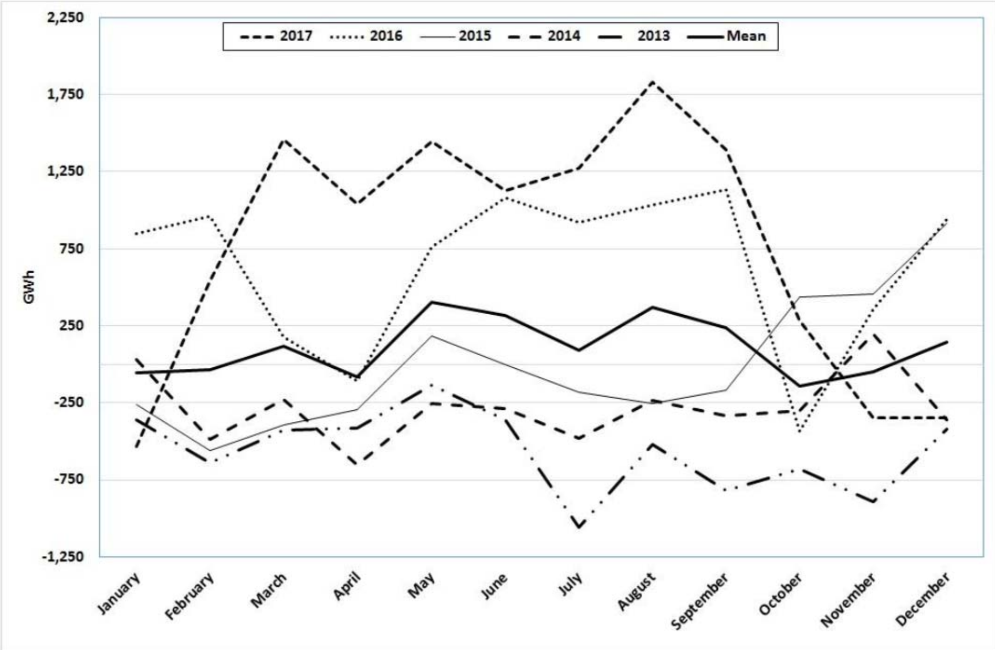
A heuristic application in Spain: Supply

Table 2. Non-thermal technologies: metered electricity / installed capacity (Source: REE).

	Hydro		Wind		Solar		Cogeneration		Others	
Month	*Average*	*Std.Dev.*	*Average*	*Std.Dev.*	*Average*	*Std.Dev.*	*Average*	*Std.Dev.*	*Average*	*Std.Dev.*
1	0.2828	0.1372	0.3081	0.0576	0.1123	0.0239	0.4826	0.0427	0.5406	0.0583
2	0.2721	0.1309	0.3237	0.0660	0.1540	0.0405	0.4856	0.0471	0.5393	0.0617
3	0.2665	0.1179	0.3137	0.0522	0.2008	0.0303	0.4682	0.0525	0.5320	0.0541
4	0.2580	0.0942	0.2914	0.0653	0.2336	0.0192	0.4627	0.0543	0.5096	0.0629
5	0.2439	0.0631	0.2353	0.0362	0.2814	0.0247	0.4557	0.0452	0.5136	0.0476
6	0.2099	0.0449	0.2229	0.0509	0.3105	0.0310	0.4556	0.0404	0.5292	0.0517
7	0.1692	0.0327	0.2173	0.0472	0.3287	0.0258	0.4561	0.0398	0.5339	0.0603
8	0.1351	0.0281	0.2108	0.0457	0.2982	0.0265	0.4073	0.0276	0.5330	0.0651
9	0.1287	0.0246	0.2056	0.0431	0.2474	0.0245	0.4588	0.0393	0.5341	0.0553
10	0.1419	0.0355	0.2520	0.0586	0.1865	0.0224	0.4686	0.0416	0.5368	0.0510
11	0.1971	0.0590	0.3045	0.0605	0.1288	0.0209	0.4804	0.0443	0.5234	0.0523
12	0.2414	0.1038	0.2990	0.0660	0.1068	0.0126	0.4721	0.0464	0.5262	0.0565

A heuristic application in Spain: Supply

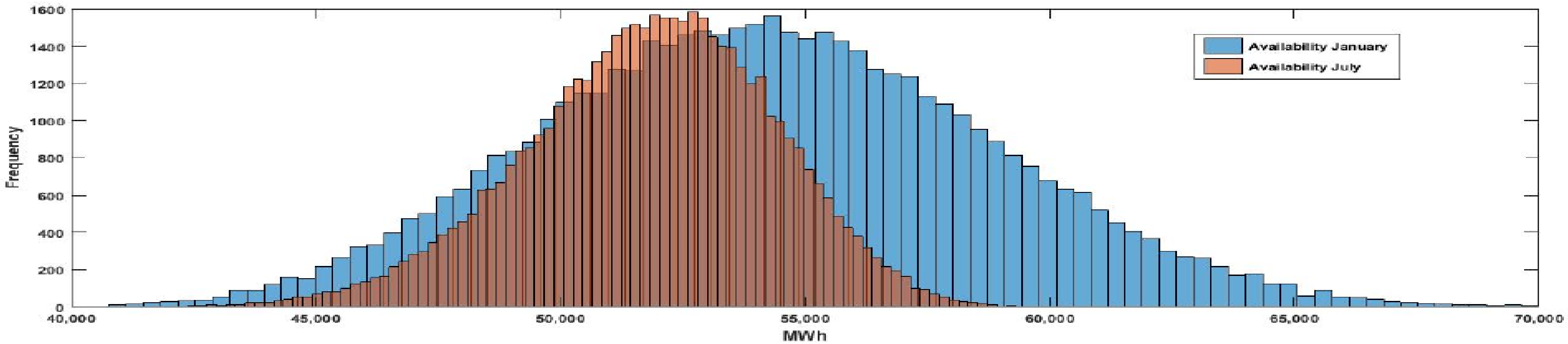
Table 3. Peninsular Spanish electricity transmission network (Source: REE).						
	2012	*2013*	*2014*	*2015*	*2016**	*Average*
Network availability (%)	97.78	98.21	98.19	97.94	98.33	98.09
	2010	*2011*	*2012*	*2013*	*2014*	*Average*
Transmission losses (%)	9.18	8.93	8.73	9.48	9.60	9.19



A heuristic application in Spain: Supply

Table 4. Descriptive statistics of simulations (from 2017 data).

	Generation (MWh)				Load factor
Month	*Average*	*5%*	*1%*	*0.1%*	*(%)*
1	54,218	41,096	39,489	37,056	54.6
2	54,355	41,113	40,091	38,897	54.7
3	53,897	41,321	39,960	37,764	54.3
4	53,152	40,443	39,494	39,066	53.5
5	51,556	41,479	40,236	38,922	51.9
6	52,635	42,401	41,099	40,007	53.0
7	51,819	42,796	41,645	40,626	52.2
8	50,451	41,762	40,819	39,223	50.8
9	50,233	41,875	40,445	39,331	50.6
10	49,979	40,316	39,427	37,562	50.3
11	52,353	41,066	39,704	38,774	52.7
12	53,127	40,534	39,216	38,297	53.5



A heuristic application in Spain: Adequacy metrics

- Matching demand and supply:
  - Take a single simulation run
  - Look for the hourly peak demand in it
  - Check the month when it took place
  - Compare with supply in that month
  - Compute the ENS (if any) as the difference of both
  - Then repeat the process for the second-highest hourly demand …

- We repeat this procedure 50,000 times for hourly demand every day over the year.

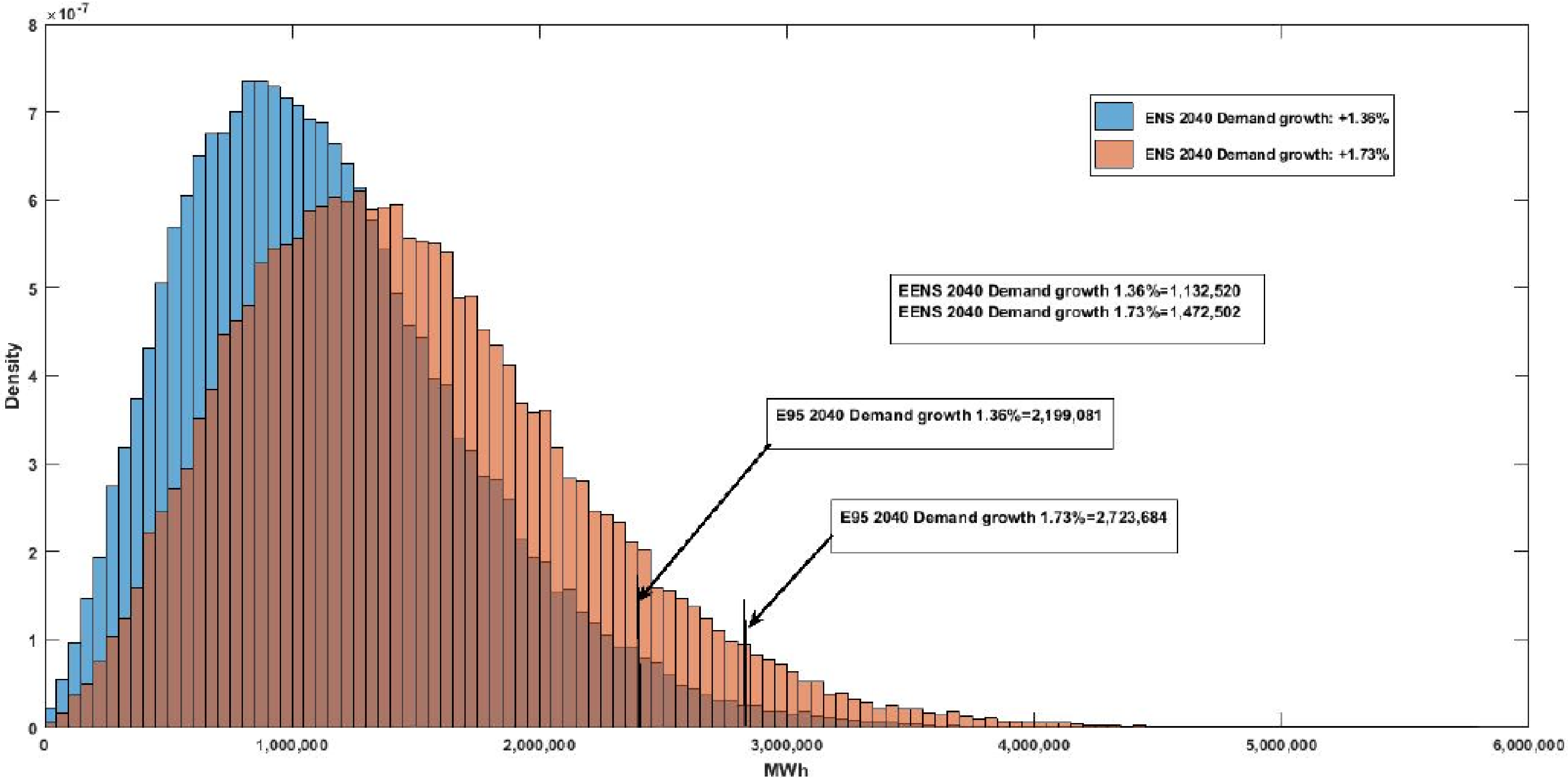
- Hence we calculate the six generation adequacy metrics.

A heuristic application in Spain: Adequacy metrics

Table 5. Peninsular system: Simulated mismatch between supply and demand.

		Demand growth: +1.36% (D_1)				*Demand growth: +1.73% (D_2)*			
	2017	*2020*	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
AD	253,082	263,621	302,026	346,026	396,436	266,564	316,909	376,762	447,920
MHD	42,398	44,013	49,858	56,486	64,001	44,463	52,107	61,077	71,603
AC	99,311	113,232	118,430	120,948	132,648	110,832	123,630	134,648	159,548
EENS	23	48	20,316	1,132,520	2,456,922	85	38,654	1,472,502	2,941,904
E95	0	0	105,809	2,199,081	3,975,367	0	175,239	2,723,684	4,673,045
LOLE	1.44	2.54	559.06	13,093.19	18,367.41	4.27	950.36	14,431.38	18,487.07
L95	0	0	2,280	18,900	21,600	0	3,420	19,800	21,660
LOLP	0.55	0.88	54.14	100	100	1.36	68.30	100	100
RM	1.34	1.57	1.37	1.14	1.07	1.49	1.37	1.20	1.23

A heuristic application in Spain: Adequacy metrics



Sensitivity analyses

Table 6. Simulated mismatch between supply and demand: Sensitivity analyses (2030, 2040).

		(S_1, D_1)		(S_1, D)		(S_1, D_1^-)		(S_1^+, D_1^-)	
	2017	*2030*	*2040*	*2030*	*2040*	*2030*	*2040*	*2030*	*2040*
AD	253,082	302,026	346,026	253,082	253,082	302,026	346,026	302,026	346,026
MHD	42,398	49,858	56,486	42,398	42,398	47,365	53,661	47,365	53,661
AC	99,311	118,430	120,948	118,430	120,948	118,430	120,948	121,430	126,948
EENS	23	20,316	1,132,520	226	12,259	6,382	663,736	1,415	151,248
E95	0	105,809	2,199,081	0	71,768	40,613	1,462,635	4,814	483,212
LOLE	1.44	559.06	13,093.19	10.24	340.06	204.35	9,358.89	53.01	2,945.50
L95	0	2,280	18,900	0	1,620	1,200	15,900	420	7,500
LOLP	0.55	54.14	100	2.81	41.34	28.79	99.96	10.40	93.72
RM	1.34	1.37	1.14	1.79	1.85	1.50	1.25	1.56	1.37

Conclusions

- SoS ranks high in the energy and environmental policy agenda.
- Focus: system's ability to meet demand continuously/reliably in the long run.
- Assess generation adequacy from a physical/technical viewpoint.
- Develop a stochastic model:
  - Maximum hourly demand as a function of annual demand
  - Thermal stations can be either 'on' or 'off' with specific probabilities
  - Renewable stations display a random load factor
  - Mismatches between demand and supply allow compute adequacy metrics
- Demonstrate the model by example: mainland Spain (an 'electric island')
  - Coal/nuclear constant up to 2020, decline in 2030, closure in 2040; gas constant
  - Non-thermal technologies grow more or less according to growth in demand

- The risk profile of power shortages does change: more volatile power supply.
- Some measures to offset this: demand response, storage, inter-connectors, …