SolarPACES 2018
Solar Power & Chemical Energy Systems
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STE Can Replace Coal, Nuclear and nearly Gas as Demonstrated in an Hourly Simulation over 4 Years in the Spanish Electricity Mix

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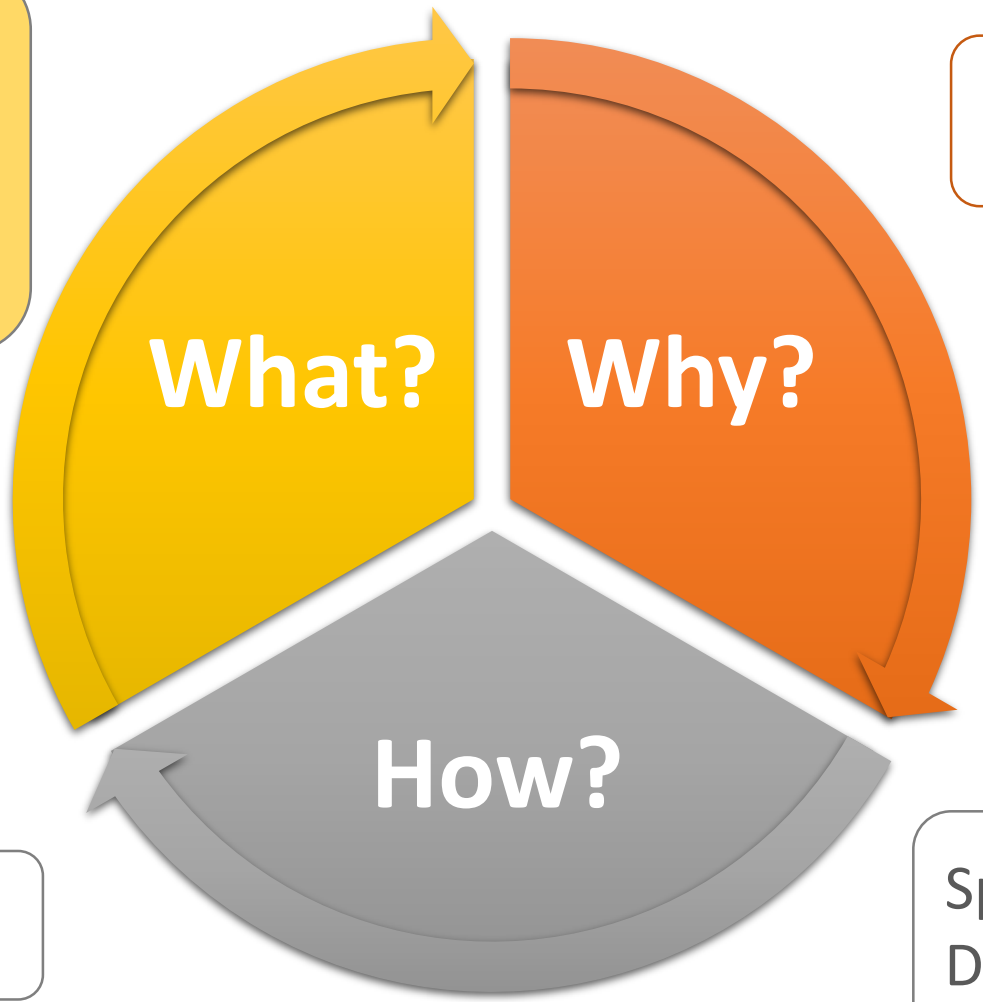
Session 3-D: Policy & Marketing

PROTERMO SOLAR

Agenda

Demonstration that STE, smartly blended with other RES, can replace Coal, Nuclear and nearly Gas



Energy Political Context in Europe & Spain

Report Methodology

Spanish Electricity Mix Raw Data & Envisioned STE Role

Political Context in Spain: Energy Transition towards being compliant with EU RES targets

Why?

Experts Committee Report: *Recommendations for the decarbonization of the Spanish Energy Sector – (ExpCom)*

STE / CSP: no ad. Capacity

Motion of censure Government Change

Integrated National Energy and Climate Plans

2030 EU RES TARGET = **30%** final energy consumption

2030 EU RES TARGET = **32%** final energy cons.

July 2017 — **April 2018** — **June 2018** — **December 2018**

Experts Committee Formation: 14 prestigious energy experts who were chosen by different political parties and unions

Base document to be followed in the Energy Transition Law

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Demonstrate that STE/CSP shall be considered in the path towards the descarbonization of the electrical system in Spain

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Why hadn't been additional STE/CSP capacity considered by the Experts Committee?

Why?

Experts Committee Report *(ExpCom): Recommendations for the decarbonization of the Spanish Energy Sector*

STE / CSP: no ad. Capacity

We needed a different approach! Fast, robust and reliable allowing to show quantitatively STE / CSP value proposition

Use of capacity expansion models

MASTER SO
ENTSOE

Optimization Criteria

- Minimize generation costs
  - PV and Wind → chosen technologies

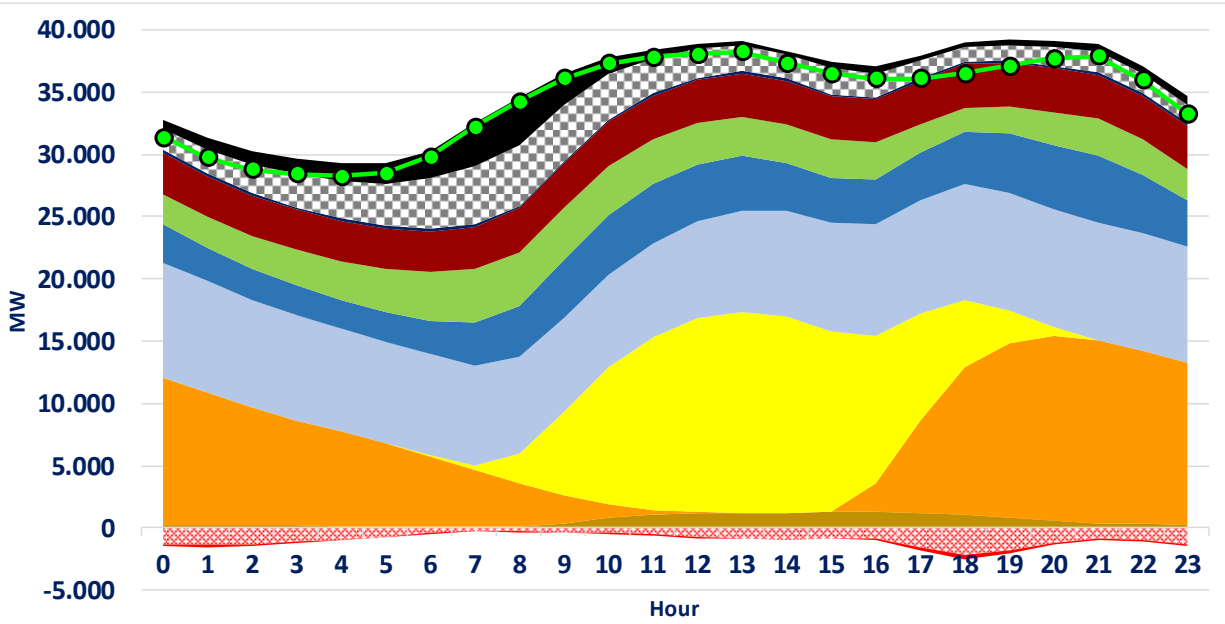
Drawbacks:

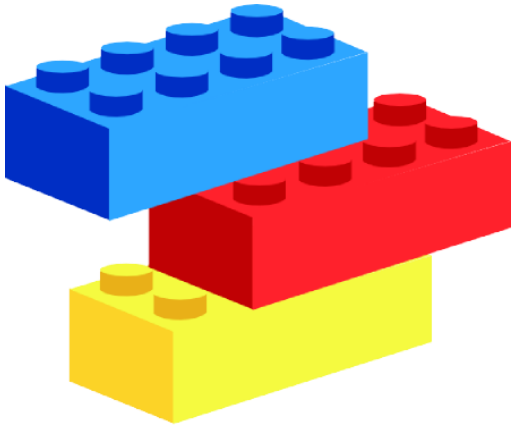
- Do not prioritize decarbonization
- End up with unfeasible generation fleet, both from technical and investor points of view
- Do not understand the dispatch flexibility of some renewables like STE or biomass
- The generation costs considered for STE plants were not updated

Fundamental principles: The distinct characteristics of the renewable generation technologies

How?

- **Satisfying the demand at any time is about putting together the appropriate generation units**
- The goal of planning is
  - To achieve a carbon free generation system
  - To ensure quality of supply and grid stability
  - At an affordable cost (not minimum)

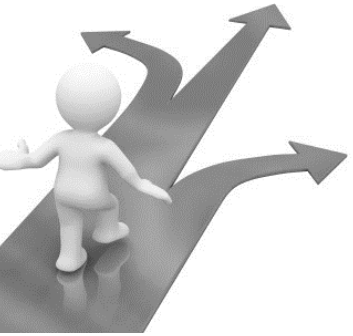




- ✓ **Wind and Sun will be the pillars of electricity** generation in the future
  Big hydro and biomass will also contribute with dispatch capabilities
- ✓ But **Wind Parks and PV plants deliver only when the resource is available** and they have seasonal and hourly constraints.
- ✓ The **right generation pieces** should be put together **to satisfy the demand in the optimum way**

Envisioned STE role: understanding which dispatch profile better suits in the future electrical system

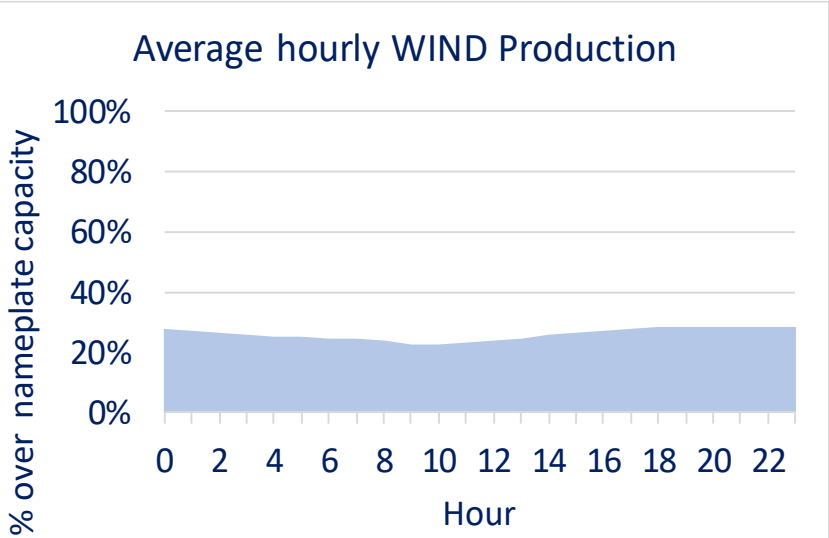
How?

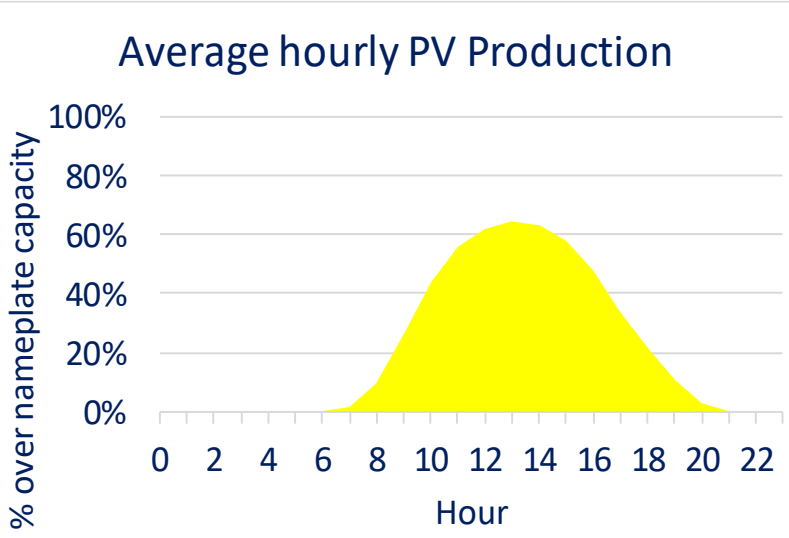


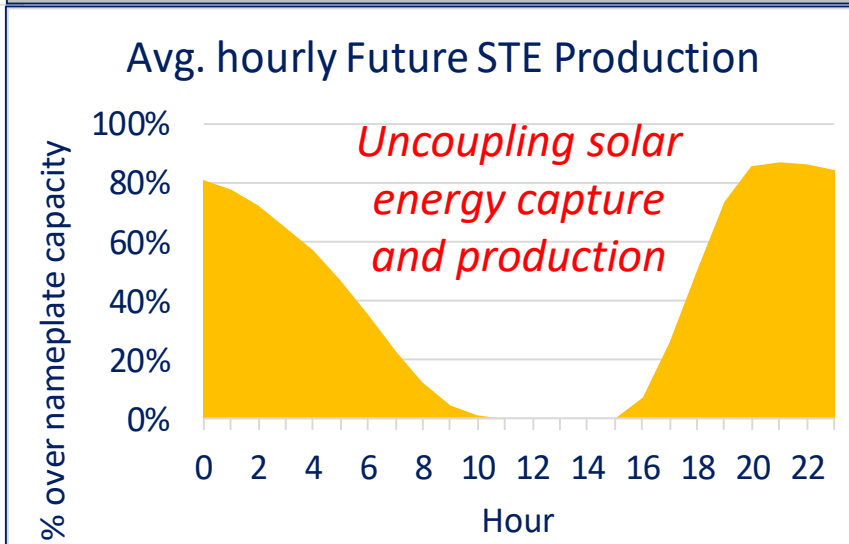
1. Build up a database with actual hourly data of the Spanish electrical system broken down by energy source along 4 years (2014-2017) → Matrix 35.064 hours x 12 columns (demand, existing solar thermal, solar photovoltaic, wind, hydropower, pumping, biomass & biogas, cogeneration, non-renewable waste, import, export, combined cycles). (Source: REE, Spanish TSO)

2. Hourly Analysis of Variable RES dispatch profile over this period

We need something else…







Envisioned STE Role for future plants

Methodology: Building up 4 potential hourly scenarios for 2030

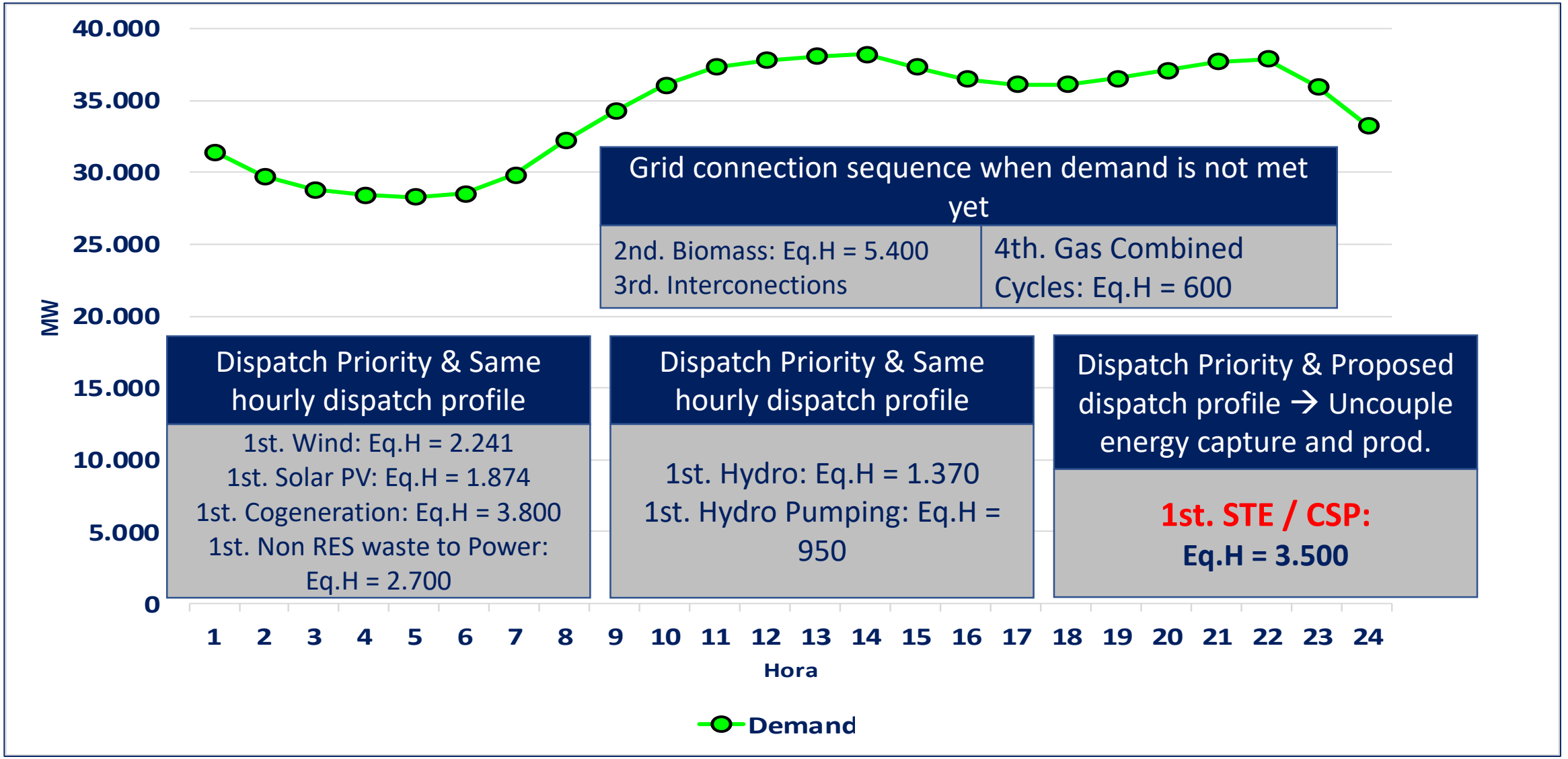
How?

INPUTS	ASSUMPTIONS	OUTCOME
Generation data of all technologies in previous years Takes into account **actual meteorological conditions in Spain along 4 years.** Sun, wind and water potential is hourly shown in this matrix	**Proposed fleet in 2030** • Same Total RES installed capacity than Exp.Com Report **Demand forecast by 2030** • Same 2030 Spanish expected demand than Exp.Com Report • Same demand profile for 2030 than the actual ones for the analyzed period **Future STE plants dispatch profile** • Similar to DEWA Project	What if 2030 is like either 2014 (2030'14), 2015 (2030'15), 2016(2030'16) or 2017(2030'17) regarding renewable resources, or the average of them (2030'M)? ✓ How much backup is required? ✓ Which is the generation cost? ✓ Which is the electrical system emissions level?
Matrix 35.064 x 12 = 420.768 hourly data of 2014, 2015, 2016, 2017		Matrix 35.064 x 13 = 455.832 hourly data of 2030'14,15,16,17

Methodology: Proposed sequence for meeting demand needs.

TSO should maximize the reduction of CO_2 emissions

How?



Methodology: STE/CSP & PV Complementarity.

Avoiding overlapping with PV at full capacity

How?

STE/CSP 3.500 Eq.H dispatch profile

STE

Month/Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total Monthly
1	7%	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	9%	13%	14%	14%	13%	11%	9%	100%
2	7%	5%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	8%	12%	13%	13%	12%	11%	9%	100%
3	8%	8%	7%	6%	5%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	1%	5%	8%	9%	10%	9%	9%	9%	100%
4	8%	8%	7%	7%	6%	5%	4%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	2%	4%	7%	9%	9%	9%	9%	100%
5	8%	8%	8%	7%	7%	6%	5%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	2%	4%	6%	8%	8%	8%	8%	100%
6	7%	7%	6%	6%	6%	6%	5%	5%	4%	3%	2%	1%	0%	0%	0%	0%	1%	3%	5%	6%	7%	7%	7%	7%	100%
7	6%	6%	6%	6%	6%	6%	6%	6%	5%	4%	2%	1%	0%	0%	0%	0%	1%	3%	5%	6%	6%	6%	6%	6%	100%
8	7%	7%	7%	6%	6%	6%	5%	5%	4%	3%	1%	0%	0%	0%	0%	0%	1%	3%	5%	6%	7%	7%	7%	7%	100%
9	8%	7%	7%	6%	6%	5%	4%	3%	2%	1%	0%	0%	0%	0%	0%	0%	1%	4%	6%	8%	8%	8%	8%	8%	100%
10	8%	7%	6%	4%	3%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	6%	10%	11%	11%	11%	10%	9%	100%
11	7%	5%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	10%	13%	13%	13%	12%	11%	9%	100%
12	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	12%	15%	15%	15%	14%	11%	8%	100%

PV 1.800 Eq.H dispatch profile

PV

Month/Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total Monthly
1	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	10%	14%	16%	16%	15%	13%	8%	3%	0%	0%	0%	0%	0%	0%	100%
2	0%	0%	0%	0%	0%	0%	0%	0%	1%	6%	10%	13%	14%	15%	14%	12%	9%	5%	1%	0%	0%	0%	0%	0%	100%
3	0%	0%	0%	0%	0%	0%	0%	0%	3%	7%	10%	12%	13%	13%	13%	11%	9%	6%	3%	0%	0%	0%	0%	0%	100%
4	0%	0%	0%	0%	0%	0%	0%	0%	2%	5%	8%	10%	12%	12%	12%	12%	10%	8%	6%	3%	0%	0%	0%	0%	100%
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6	0%	0%	0%	0%	0%	0%	0%	1%	3%	6%	8%	10%	11%	11%	11%	11%	10%	8%	6%	4%	2%	0%	0%	0%	100%
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11	0%	0%	0%	0%	0%	0%	0%	0%	2%	7%	12%	14%	16%	15%	14%	11%	7%	1%	0%	0%	0%	0%	0%	0%	100%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	11%	15%	17%	17%	16%	12%	7%	1%	0%	0%	0%	0%	0%	0%	100%

What do we claim/demonstrate?
Another mix of electricity generation is possible (and desirable)

What?

The natural complementarity of renewables in Spain (Wind / Sun and Water) together with the smartly use of STE / CSP would allow a 2030 scenario*:

- ✓ **Without coal power plants**
- ✓ **Without nuclear power plants**
- ✓ **With less support of combined cycles than in the report of the Experts Committee Report (ExpCom)**
- ✓ **With 85.6% of renewable generation with very few curtailments (82% less than the discharges foreseen by the ExpCom)**
- ✓ **With very reduced emissions (half that provided by the Exp.Com)**
- ✓ **Achieving a 34% penetration of renewable energy in the final energy demand**
- ✓ **Fulfilling EU objectives**
- ✓ **And less than 5 c€ / kWh generation cost**

This is a **true Energy Transition** with enormous additional benefits for the economy of the country

*Note: The results of this report do not correspond to theoretical simulations, but to the projection made from of generation time data in real years of the mix considered

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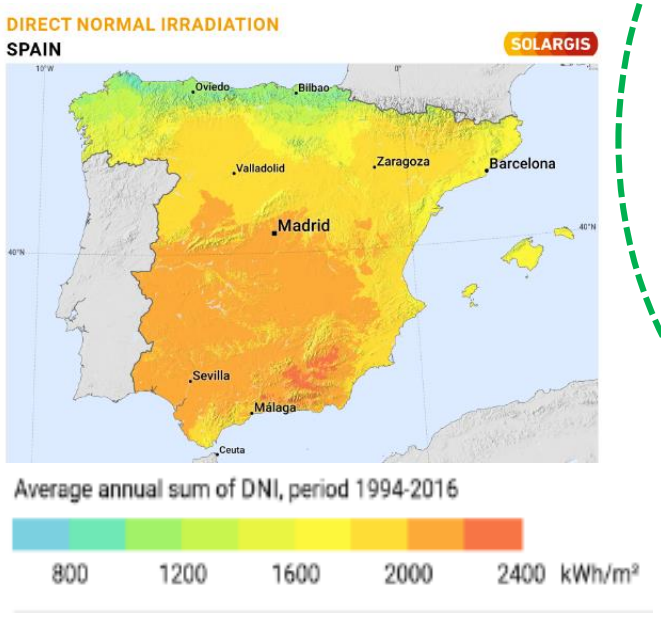
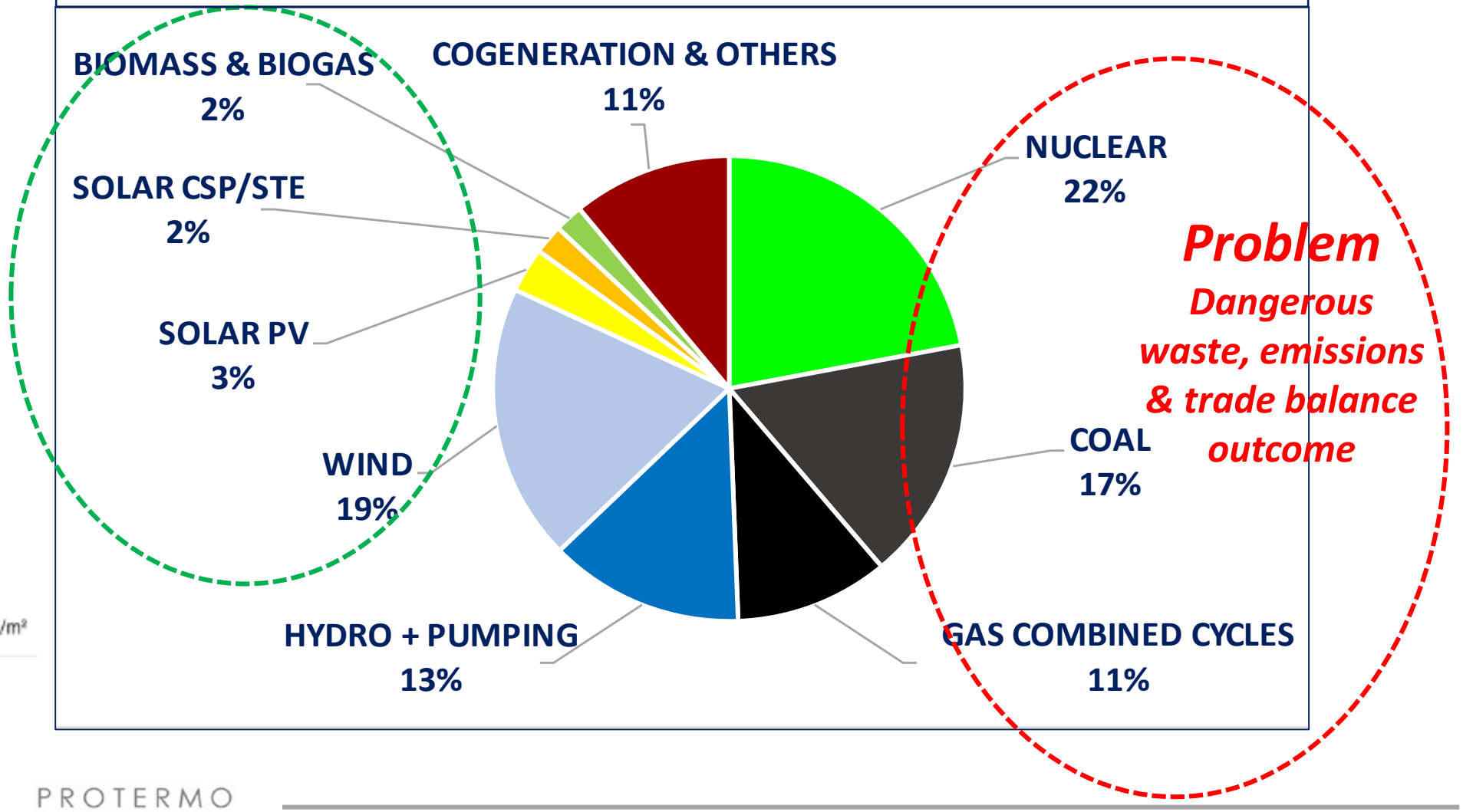
What does it need to be changed in the electricity mix? Where do we come from?

What?

SOLution



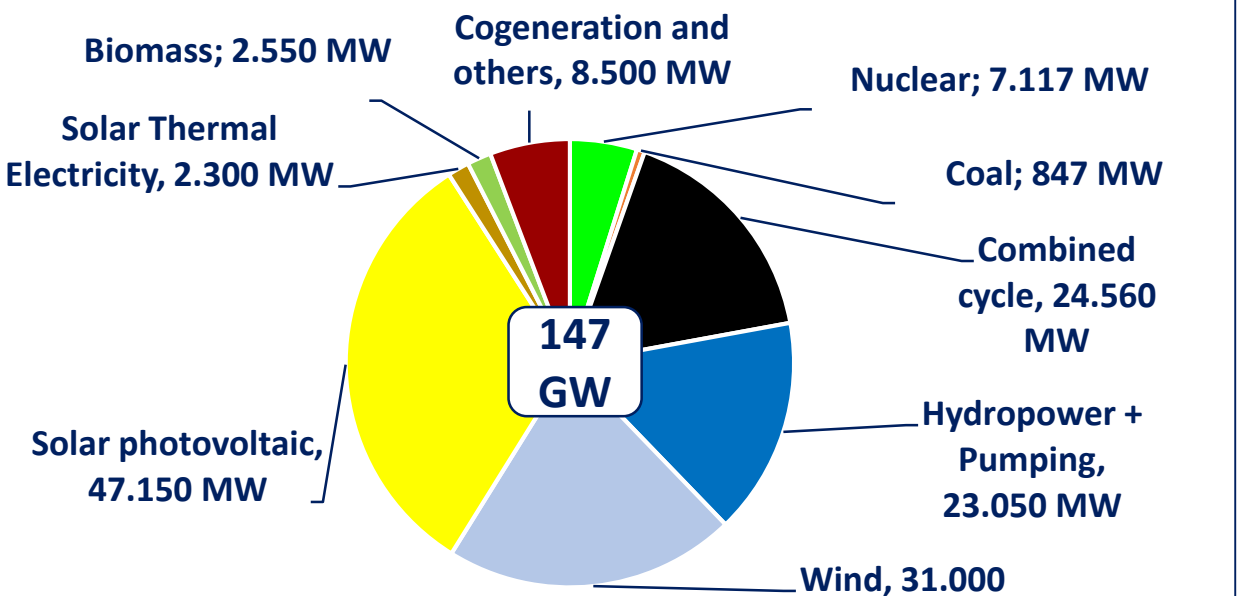
Generation Mix by energy source in Spain, average of the period [2014 – 2017]



What are the differences (Installed Capacity) between suggested solutions of the electricity mix? Exp.Com vs Protermosolar

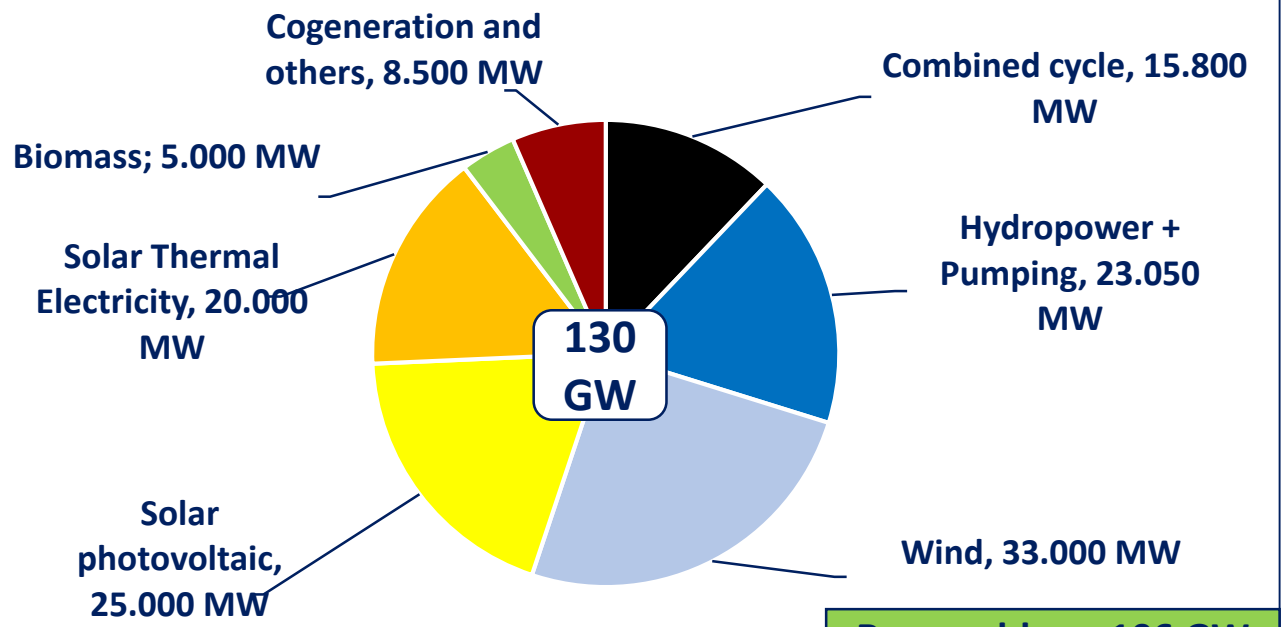
What?

MIX Commission of Experts



Renewables = 106 GW

MIX PROTERMOSOLAR (2030'M)



Renewables = 106 GW

17 GW

What are the differences (Generation) between suggested solutions of the electricity mix? Exp.Com vs Protermosolar

What?

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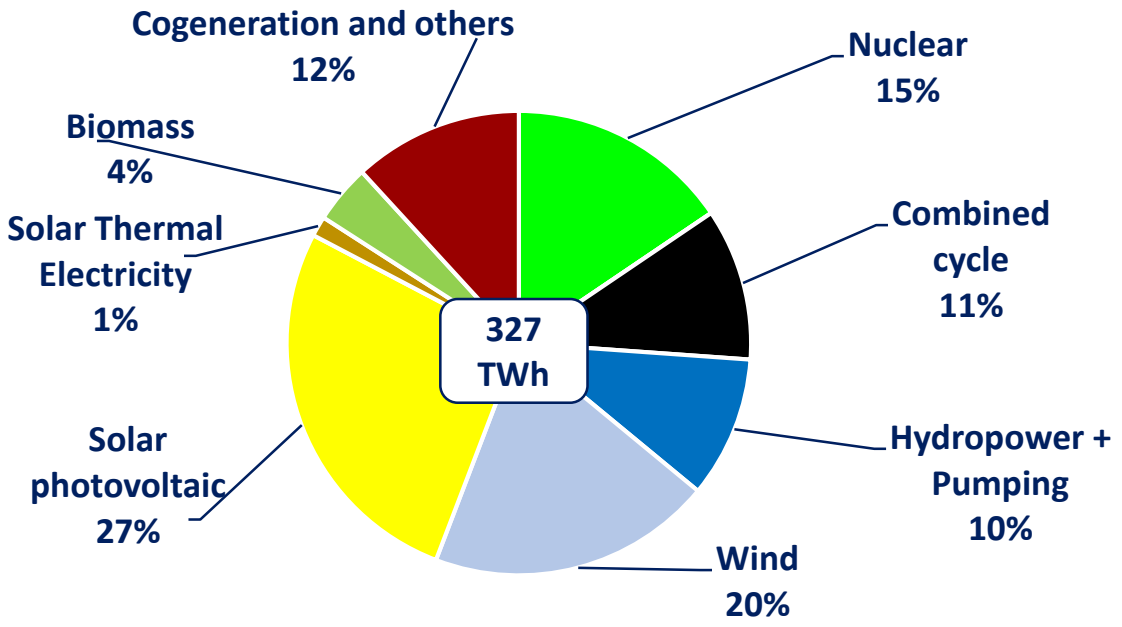
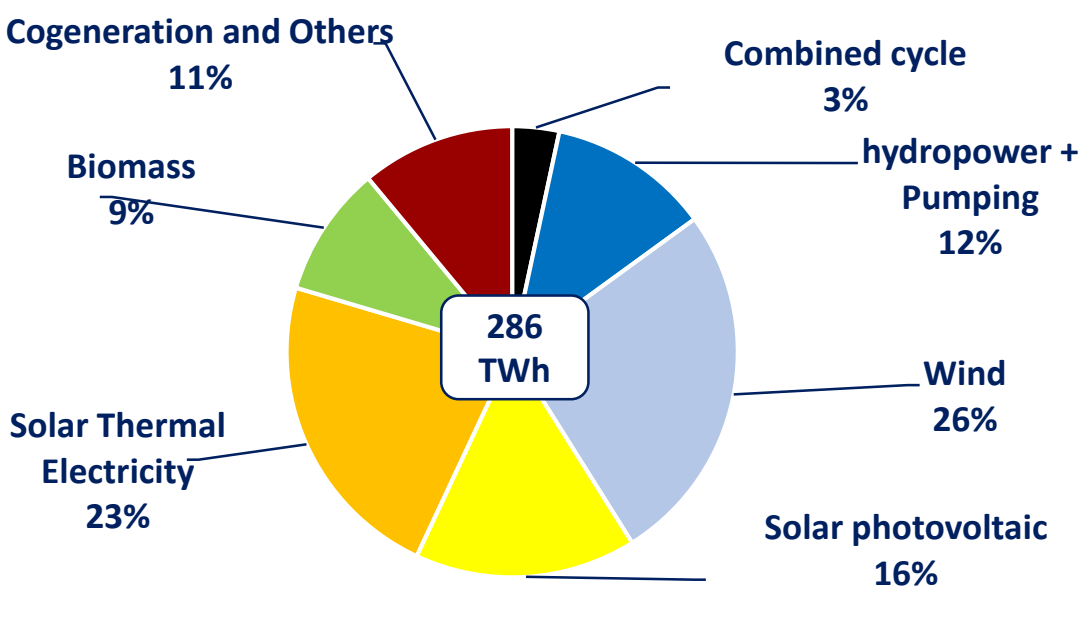


MIX PROTERMOSOLAR (2030'M)

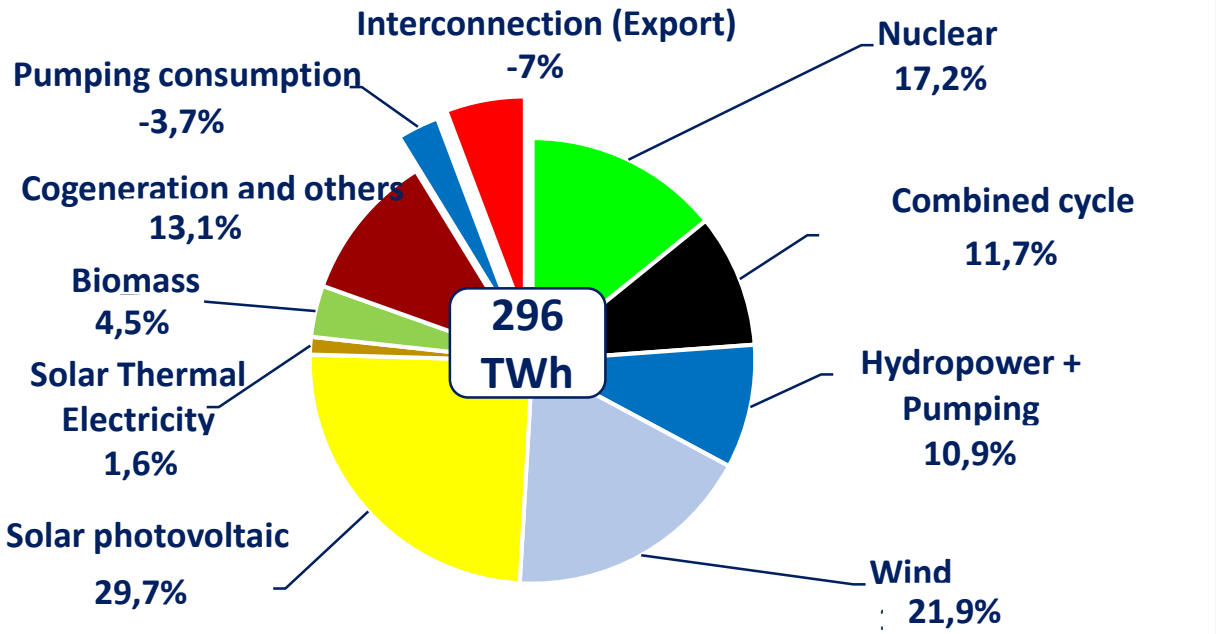


- ✓ 85.6% of electricity generation is renewable sources compared to 62.1% of the ExpCom
- ✓ Gas Combined cycles would only contribute 3.4% to the generation mix
- ✓ Carbon and nuclear would phase out of the generation system

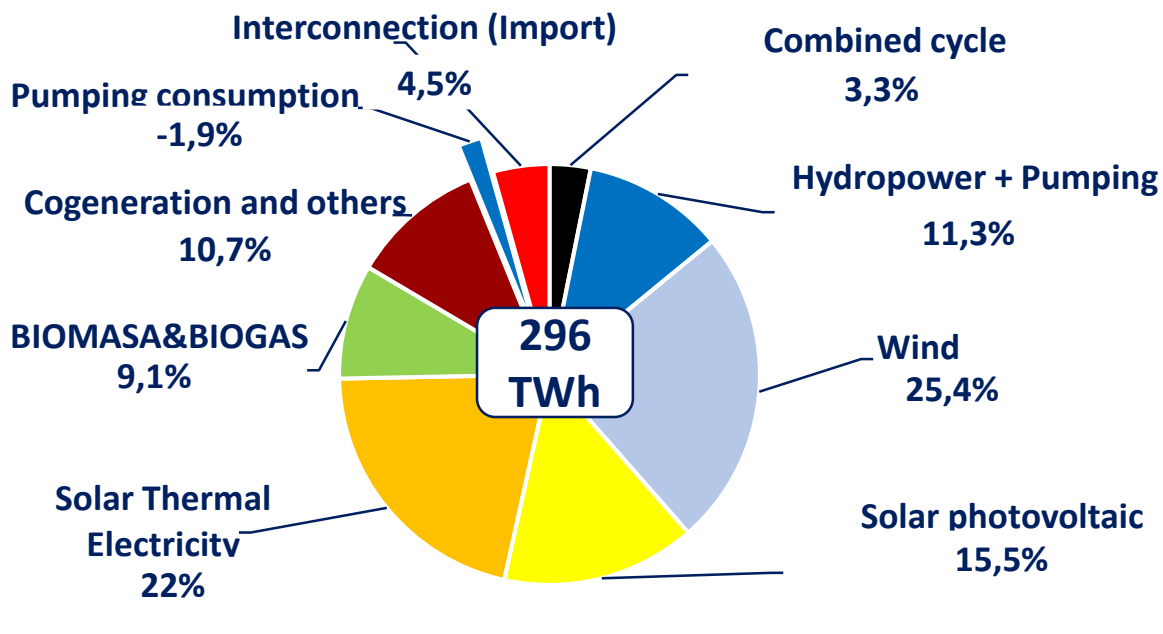
What are the differences (Demand) between suggested solutions of the electricity mix? Exp.Com vs Protermosolar

What?

MIX Commission of Experts



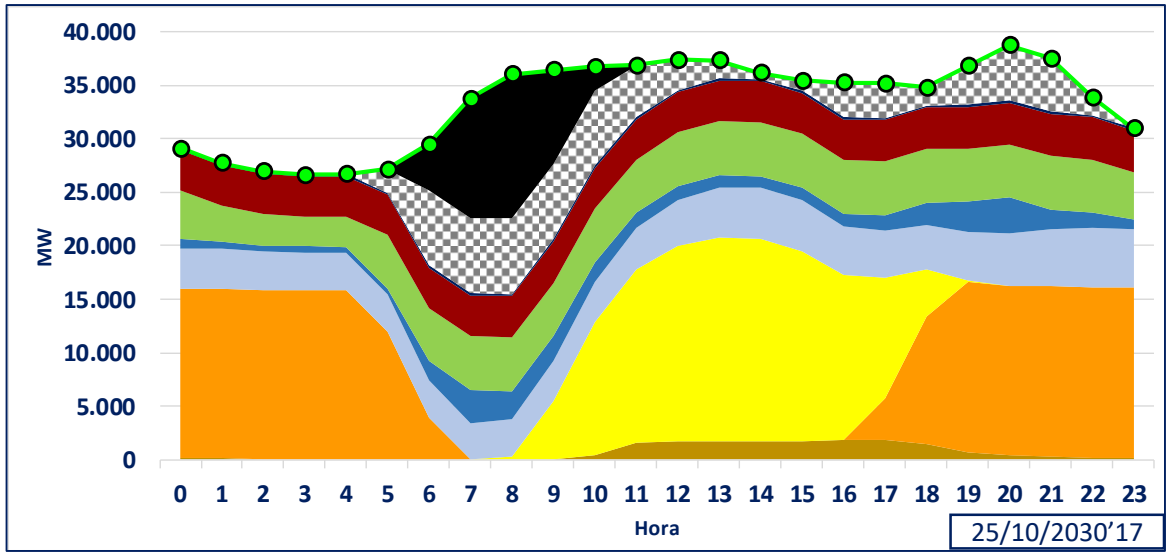
MIX PROTERMOSOLAR (2030'M)

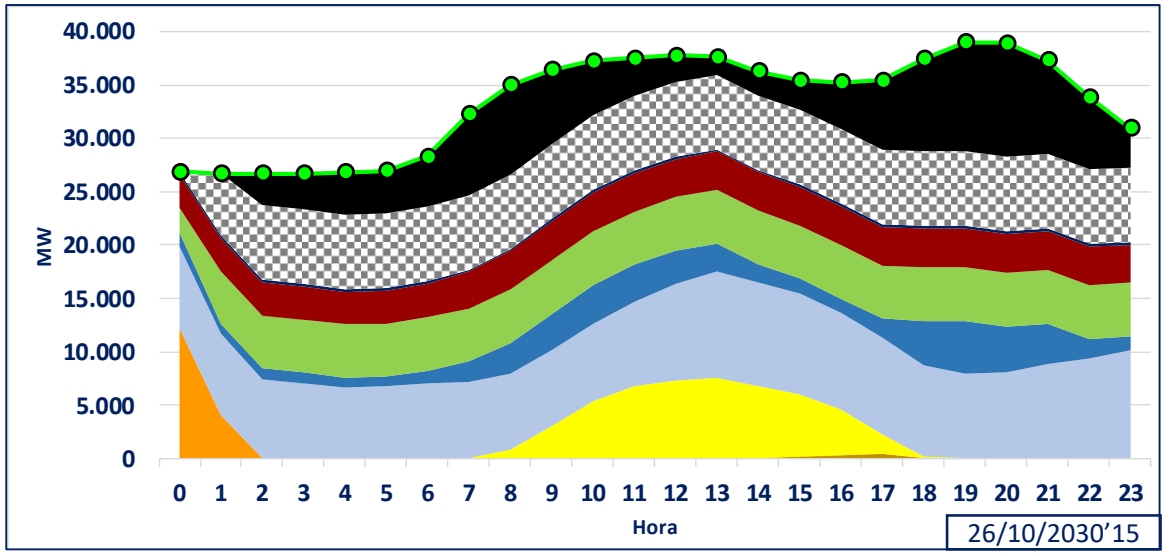


- In the mix proposed by Protermosolar the demand coverage for renewable sources is 83%, compared to 69% of the ExpCom
- Both generation mix correspond to a demand of 296 TWh. (The hydraulicity of the mix of Protermosolar (hydraulic + pumping) shown in this graph takes into account the average of the last 4 years = 33.5 TWh, a value very close to the 32 TWh of the scenario of average hydraulicity taken into account in the base case by the ExpCom
- The saturation of interconnection considered for 2030 in the scenario proposed by Protermosolar is 7 GW, both import and export, which can be considered as more conservative compared to the sum of capacity with France, Portugal and Morocco taken by ExpCom

What is behind these pie charts? → Daily analysis of cumulative production figures of 1.460 days. **AUTUMN** example of sunny and non-sunny specific days

What?





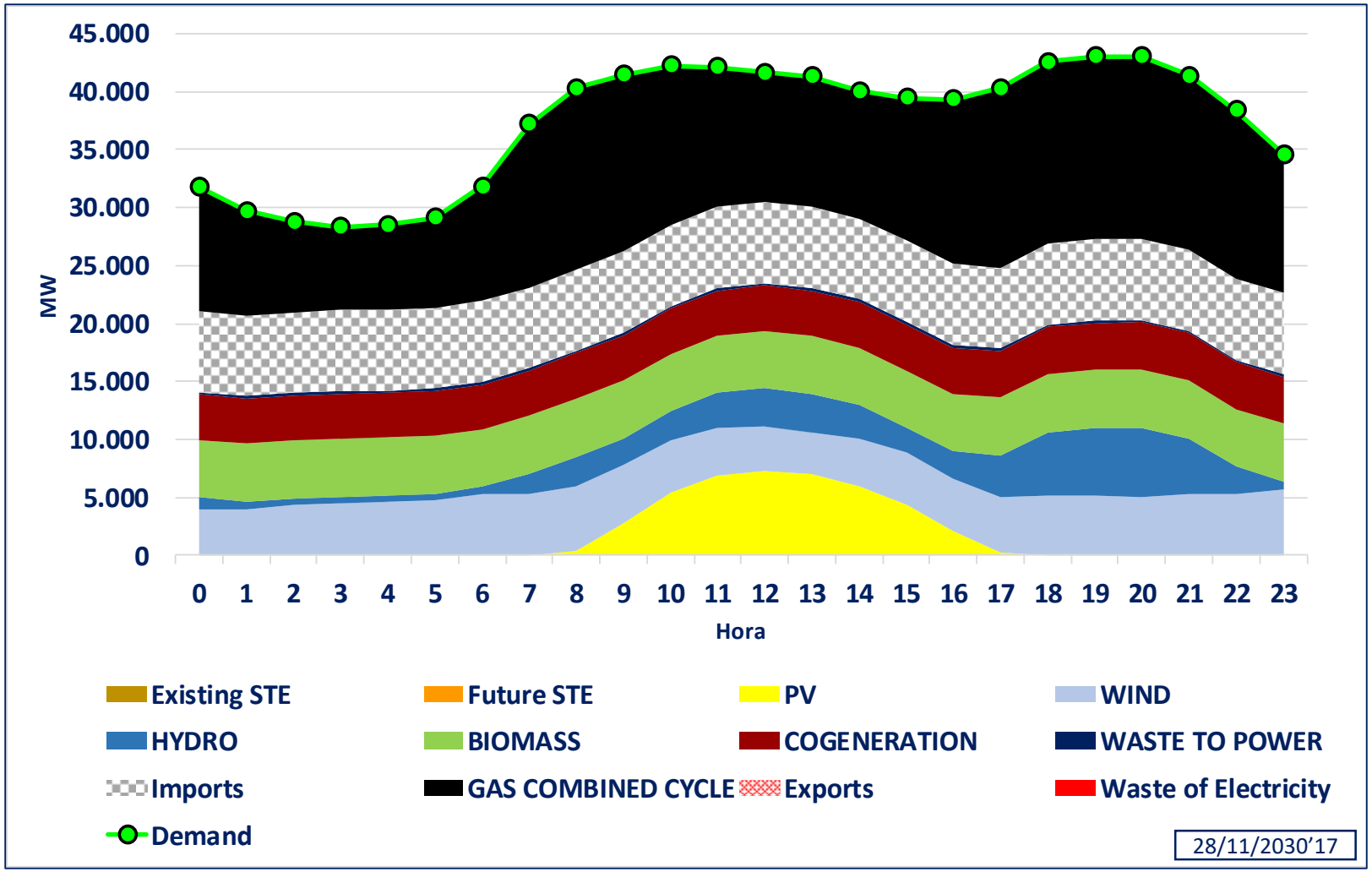
Existing STE | Future STE | PV | WIND | HYDRO
BIOMASS | COGENERATION | WASTE TO POWER | Imports | GAS COMBINED CYCLE
Exports | Curtailment | Demand

- On a sunny autumn day, the solar thermal works until late into the following night, although the decrease of solar thermal generation coincides with the absence of the photovoltaic, which implies that the combined cycles are required to cover the demand from 5 to 10 in the morning.

What if there isn't wind, sun and water at the same time? System response on the worst day of the 4 years

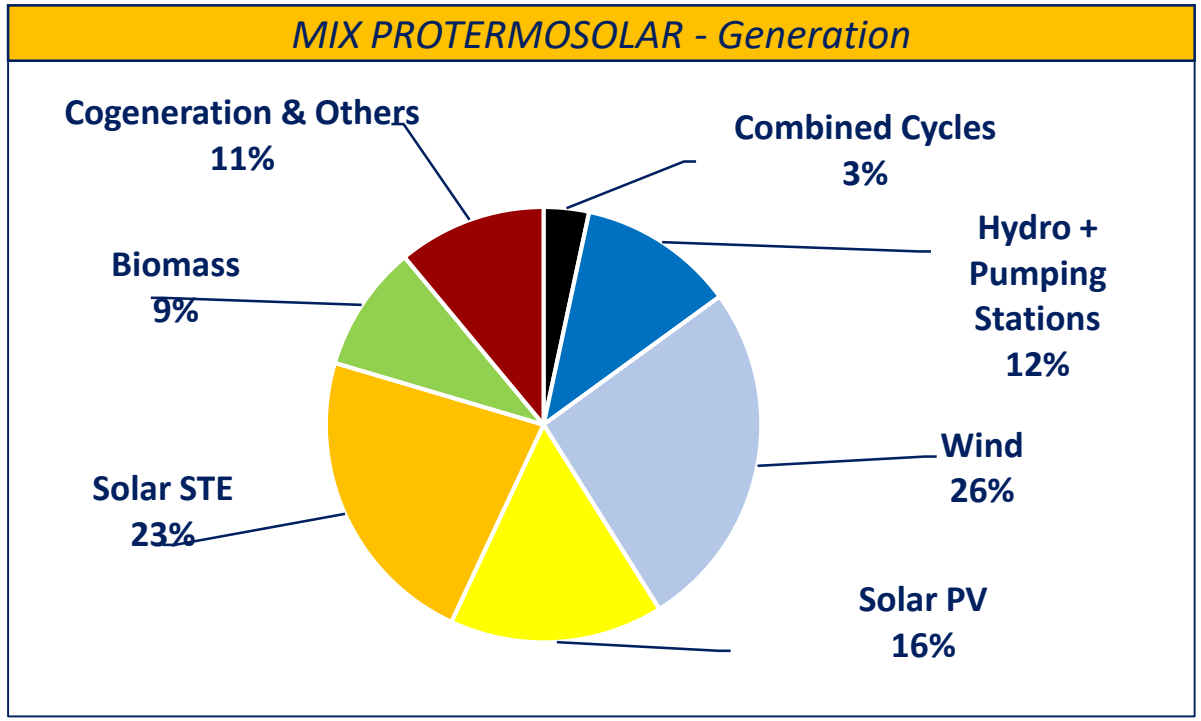
What?

The most unfavourable day of the 4 years analysed is the equivalent of November 28, 2017 projected into 2030.
The solar resource was very low, so much that the solar thermal plants could not have collected any energy during the day, when photovoltaic hardly generated and there was little wind, the hydraulic resource being also very scarce. For these reasons biomass operates at full load all the day, imports saturating interconnections and combined cycles work all day.



What about generation costs?

What?



Energy Source	Generation Cost in 2030 (€/MWh)
Gas Combined Cycle(50€/ton CO_2 - ExpCom Value)	73,83
Hydro	20
Pumping Stations	25
Wind	40
Solar PV	35
Solar STE	55
Biomass	60
Cogeneration & Others	70
Waste to Power	80
Imports	60
Exports	40
TOTAL Generation Costs	48,8

Análisis de Sensibilidad de Costes de Generación del sistema a 2025

Precio Aritmético de España	€/MWh
2017	52,24
2016	39,67
2015	50,32
2014	42,13

http://m.omie.es/reports/index.php?m=yes&report_id=411

Fuente Energética	Costes de Generación en 2025 (€/MWh)	Análisis de sensibilidad para Costes Gen a 50€(MWh)	Análisis de sensibilidad para Costes Gen a 60€(MWh)	Análisis de sensibilidad 1	Análisis de sensibilidad 2	Análisis de sensibilidad 3	Análisis de sensibilidad 4	Análisis de sensibilidad 5
Ciclo Combinado	60	60	60	60	60	60	60	60
Hidráulica	20	20	20	20	20	20	20	20
Bombeo	25	25	25	25	25	25	25	25
Eólica	42,2	42,2	42,2	42,2	42,2	40	42,2	40
Solar Fotovoltaica	36,9	36,9	36,9	36,9	36,9	35	36,9	35
Solar Termoeléctrica	67,5	56	206	90	67,5	67,5	67,5	90
Biomasa & Biogas	75,4	75,4	75,4	75,4	75,4	75,4	75,4	75,4
Cogeneración	70	70	70	70	70	70	70	70
Nuclear	40	40	40	40	50	40	40	50
Residuos no renovables	80	80	80	80	80	80	80	80
Importación	60	60	60	60	60	60	65	65
Exportación	40	40	40	40	40	40	35	35
Total Costes de Generación	50,7	50	60	52,2	51,3	49,9	50,7	52
Variación (%)	0%	-1,5%	+18,2%	+3,0%	+1,1%	-1,6%	+0,1	+2,5

Análisis de Sensibilidad de Costes de Generación del sistema a 2030

En la tabla se muestran los precios a los que podrían generar las centrales termosolares para que el coste global no fuera superior a 50 o 60 €/MWh, manteniendo las hipótesis sobre el resto de costes.
Asimismo se presentan escenarios con hipótesis de mayores precios para la termosolar o la biomasa, mayor diferencial import-export y menores precios de la eólica y la fotovoltaica. También se presenta el efecto combinado de todos ellos

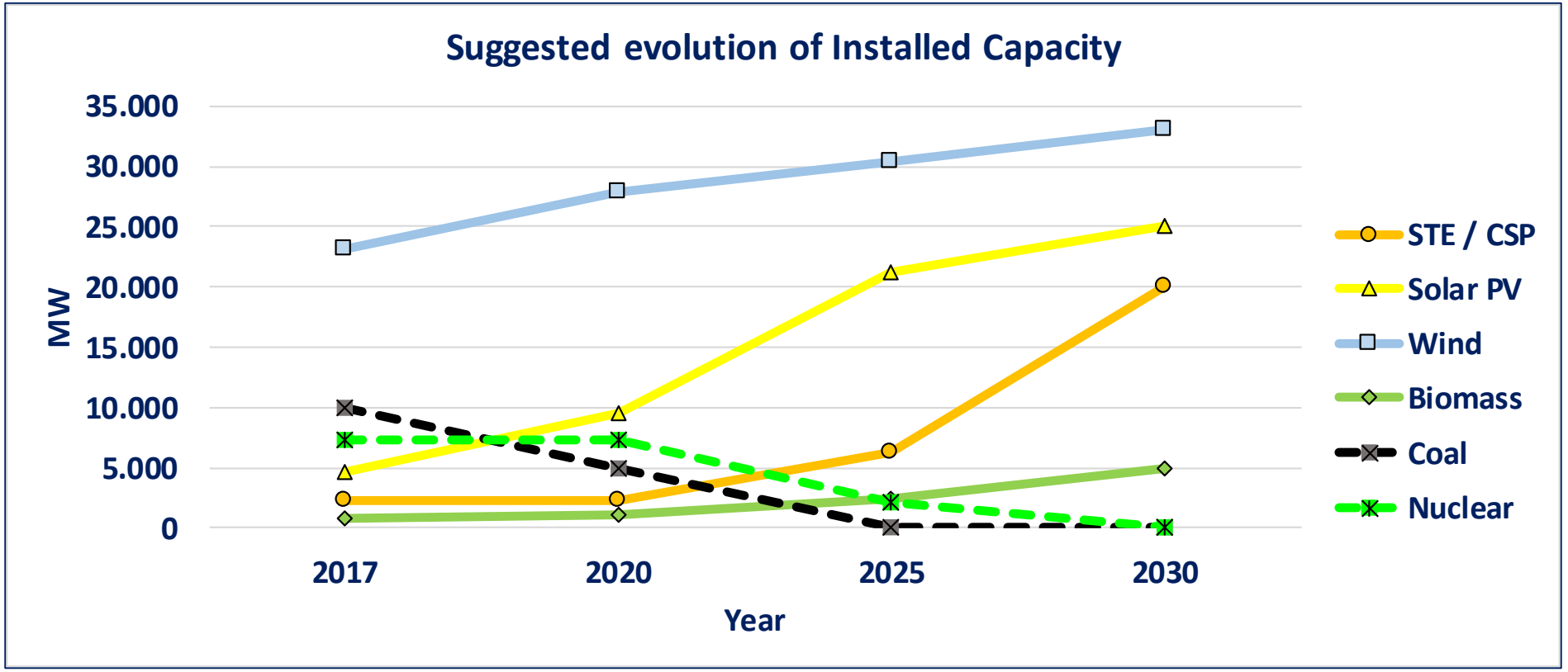
Precio Aritmético de España	€/MWh
2017	52,24
2016	39,67
2015	50,32
2014	42,13

http://m.omie.es/reports/index.php?m=yes&report_id=411

Fuente Energética	Costes de Generación en 2030 (€/MWh)	Análisis de sensibilidad para Costes Gen a 50€(MWh	Análisis de sensibilidad para Costes Gen a 60€(MWh	Análisis de sensibilidad 1	Análisis de sensibilidad 2	Análisis de sensibilidad 3	Análisis de sensibilidad 4	Análisis de sensibilidad 5
Ciclo Combinado (50€/ton CO_2)	**74**	74	74	74	74	74	74	74
Hidráulica	**20**	20	20	20	20	20	20	20
Bombeo	**25**	25	25	25	25	25	25	25
Eólica	**40**	40	40	40	40	37	40	37
Solar Fotovoltaica	**35**	35	35	35	35	32	35	32
Solar Termoeléctrica	**55**	60,5	106	65	55	55	55	65
Biomasa & Biogas	**60**	60	60	60	80	60	60	80
Cogeneración	**70**	70	70	70	70	70	70	70
Residuos no renovables	**80**	80	80	80	80	80	80	80
Importación	**60**	60	60	60	60	60	65	65
Exportación	**40**	40	40	40	40	40	35	35
Total Costes de Generación	**48,8**	**50**	**60**	**51**	**50,6**	**47,6**	**49,3**	**52,1**
Variación (%)	**0%**	**+2,48%**	**+23,02%**	**+4,51%**	**+3,75%**	**-2,51%**	**+1,06**	**+6,80**

What does it need to happen to before 2030? Different Technology needs at different timing

What?



2017 – 2020: Already awarded auctions (PV, Wind & Biomass) + PPAs

2020 – 2025: Linear increase for Wind, High penetration of PV, Small penetration of STE/CSP & Biomass

2025 – 2030: Variable RES capacity will be close to market limits. High penetration of STE/CSP & Biomass

What does it need to happen to before 2030?
Specific Technology auctions and a foreseeable RES planning

What?

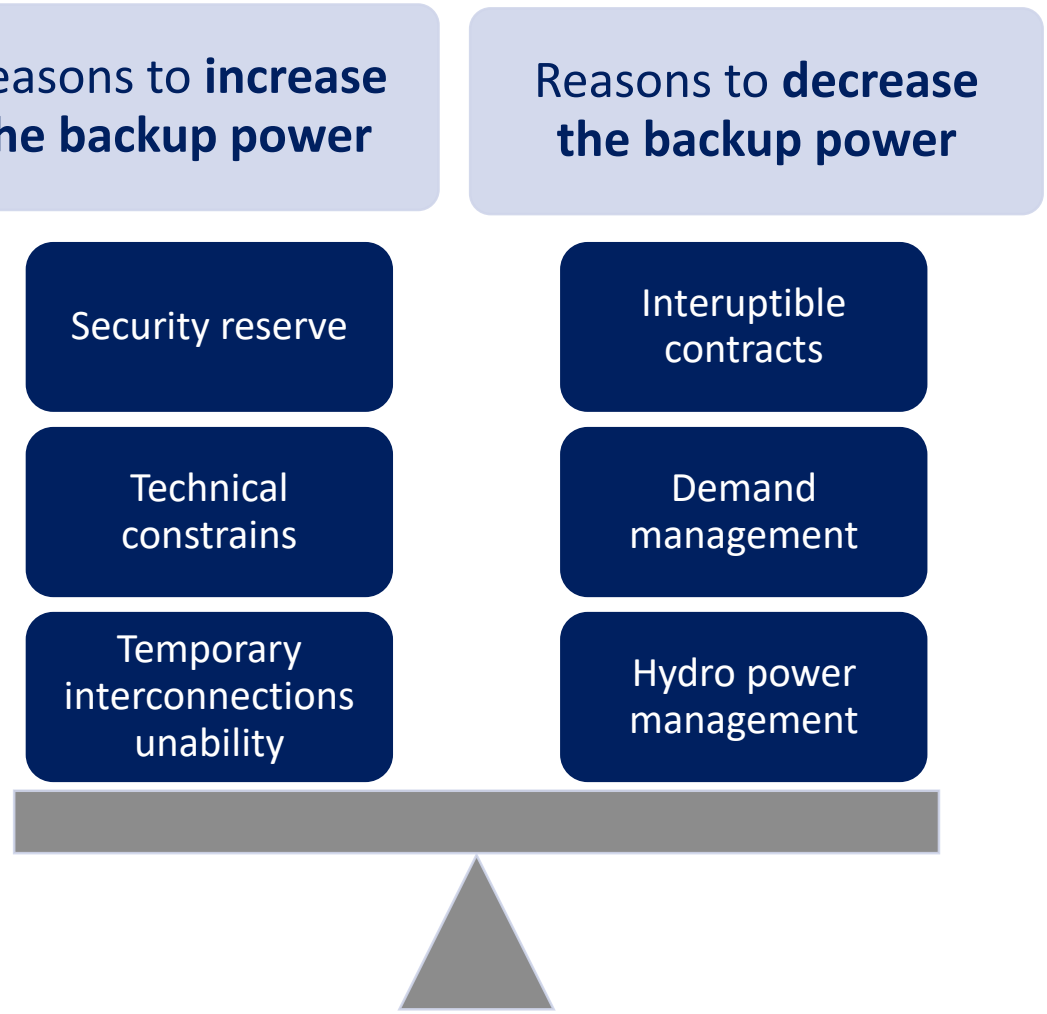
	STE / CSP		Solar PV		Wind		Biomass	
	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)
2021	75	500	40	2.700	45	514	95	200
2022	72	500	38	2.700	43	514	85	200
2023	70	500	37	2.700	42	514	75	200
2024	67	1.000	35	2.000	41	514	70	300
2025	63	1.500	32	1.500	40	514	65	400
2026	59	2.000	31	1.000	39	514	60	500
2027	54	2.925	30	701	39	514	55	536
2028	51	2.925	29	701	38	514	50	536
2029	48	2.925	28	701	37	514	50	536
2030	47	2.925	27	701	36	514	48	536
Weighted average by Technology in 2025	**67**		**37**		**42**		**75**	
Weighted average by Technology in 2030	**55**		**35**		**40**		**60**	

STE Can Replace Coal, Nuclear and nearly Gas as Demonstrated in an Hourly Simulation over 4 Years in the Spanish Electricity Mix

What have & haven't we considered in this study regarding grid technical features?; Do we need more back-up?

What?

- ✓ **Minimum requested synchronous generation** in the electricity systems is 5.500MW
- ✓ **Ramps** have been **checked** to be within the technical feasible range for:
  - ✓ Gas Combined cycles
  - ✓ Biomass
- ✓ **Interconnections** operating at full load capacity are lower than Exp.Com Report
- × The main limitation of this study is that it has been taken into consideration **Spain a unique node**
- × It has not been analyzed whether there could be or not new **network needs linked to the future location of the new electricity mix**. STE plants would be erected in the mid-south of Spain, whereas dismantled coal power plants are mainly located in the north-west of Spain.



Conclusions

Why? How? What?

- **Actual meteorological complementarity of wind, water and sun shall be deeply analyzed at country level when planning future electricity mix.** Least cost expansion models may have been designed for non-dominated RES electricity mix

- The outcomes of this study shows that **Spain could close the polluting and risky coal and nuclear power plants while sharply reducing the need of gas** combined cycles back-up **by 2030**

- A smart **combination of dispatchable and non-dispatchable shows how PV and STE shall work together, avoiding overlapping** at full capacity. This combination would lead to an unbeatable electricity cost

- Although the study refers to the Spanish case, the conclusions may apply to all Sunbelt countries. **High RES penetration is feasible when appropriate complementarity of natural resources is given**

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THANKS FOR YOUR ATTENTION

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